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MALASPINA GLACIER.

INTRODUCTION.

A DEFINITE classification of glaciers does not seem to be practicable, for the reason that various types which may be selected grade one into another through many intermediate forms. It is convenient, however, especially in teaching, to recognize three generic types termed Alpine, Piedmont and Continental glaciers; and a subordinate class designated as Tidewater glaciers, to include those which reach the ocean and give origin to bergs.

Alpine glaciers occur in many mountainous regions and have their type in the Alps where they were first studied. Several divisions dependent upon size have been recognized.

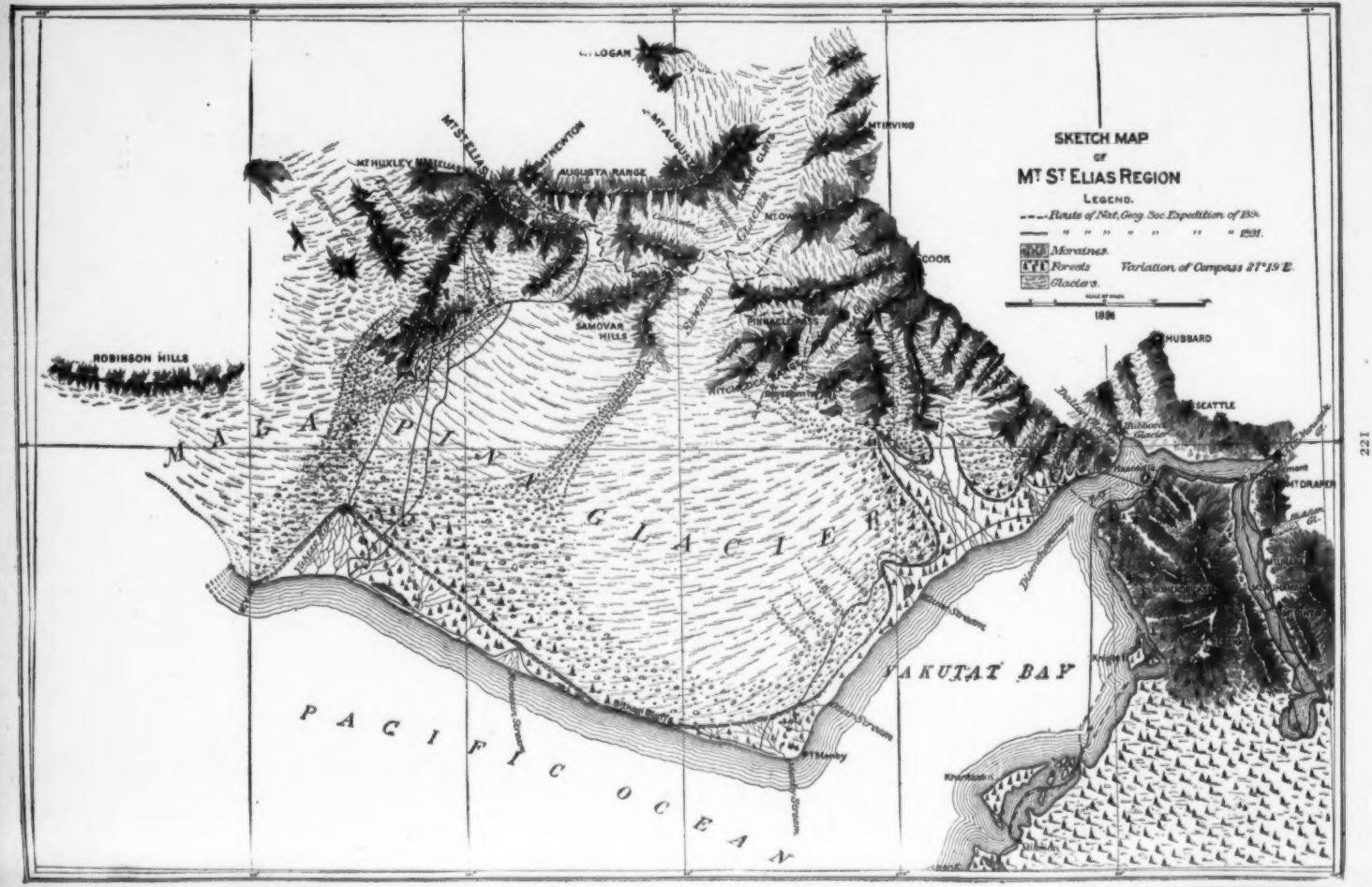
Continental glaciers as their name implies are of vast extent, and at the present time are illustrated by the ice sheets of Greenland and the Antarctic continent. The Pleistocene ice sheets of America and Europe were of this class.

Piedmont glaciers are formed on comparatively level ground at the bases of mountains where the ice is unconfined by highlands in most directions and has freedom to expand. They are fed by glaciers of the Alpine type, which spread out and unite one with another on leaving the valleys through which they descend from snow fields at higher elevations. The only known example of this class occurs in Alaska on the plain intervening between the Mt. St. Elias range and the ocean, and is the subject of this sketch.

GEOGRAPHY OF THE ST. ELIAS REGION.

The south coast of Alaska from Glacier bay on the east to the vicinity of the mouth of Copper river on the west, is bordered by a system of lofty mountains composed of many short ranges, which present steep escarpments to the south and overlook a narrow coastal-plain. At times the plain is wanting as in the vicinity of Mt. Fairweather, and the mountains rise directly from the ocean to great heights. To the north of the uplifts, facing the sea, there is an excessively rugged plateau probably about a hundred miles broad, and with a general elevation of eight or nine thousand feet. On this plateau there are hundreds of short ranges and isolated peaks rising by estimate some five or six thousand feet above the ice-filled valleys, while some of the more prominent summits have a still greater elevation. The northern border of this rugged region has been only partially explored but is known to be less precipitous than its southern face. The elevated region is destitute of both plant and animal life, and is covered with a vast névé field through which many precipitous peaks project. The southern slopes of these islands in the desert of snow are frequently bare in summer and furnish the only relief to the mantle of perpetual white. It is in this region that the ice streams supplying the Malaspina glacier have their sources.

The Tyndall glacier, shown on the accompanying map, is fed by the snow falling on the southwest portion of the Mt. St. Elias range, and flows southward with such a strong current that even after expanding on the plain at the base of the mountains and forming the western lobe of the Malaspina glacier, it continues its southward course and entering the sea forms Icy cape from which thousands of bergs are annually set adrift. Tyndall glacier has important tributaries, especially from the northern side of Robinson hills, but whether it is joined by a glacier from the elevated region to the north of the first range facing the coast, is not known. No break through which a glacier could flow has been observed in the mountain crest to be seen from the ocean, but future explorers may hope to discover such a pass.


SKETCH MAP
OF
Mt St ELIAS REGION
LEGEND.
Route of Nat. Geog. Soc. Expedition. of 1890.
" " " " " " 1891.
Moraines.
Forests
Glaciers.
Variation of Compass 27°19' E.
1891
Mt LOGAN
Mt ST ELIAS
Mt AUGUSTA
Mt IRVING
Mt HUXLEY
AUGUSTA RANGE
Mt COOK
SAMOVAR HILLS
PINNACLE PEAK
HITCHCOCK RANGE
HUBBARD
SEATTLE
Mt DRAPER
ROBINSON HILLS
MALASPINA GLACIER
YAKUTAT BAY
PACIFIC OCEAN

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The Agassiz glacier is formed by the union of many high-grade ice-streams on the eastern and northern slopes of the St. Elias range, and on the southern face of the equally precipitous Augusta range. All of these tributaries have been seen and are indicated in a rough way on the accompanying map.

Seward glacier is the principal feeder of the Malaspina ice sheet. Its most distant tributaries have their sources far to the north of the Augusta range, in the general névé field covering the main mountain mass. Scores, if not hundreds, of secondary glaciers unite to form the trunk stream which is fully three miles broad where best defined, and probably not less than sixty or seventy-five miles long.

Besides the great glaciers enumerated above there are several smaller ice-streams of the same type, such as the Marvine, Hitchcock, Lucia, etc., each of which is eight or ten miles in length and flows through a deep well-defined valley. Between these various trunk streams there are scores of high-grade glaciers that originate in deep cirques in the southern face of the mountains or in some instances, on the rugged slopes themselves where there are no depressions, and descend to and merge with the vast plateau of ice skirting the ocean.

Before giving special attention to the Malaspina glacier it may be well to glance at a few other geographical conditions which influence its existence.

The climate of southern Alaska adjacent to the coast is mild and uniform. The summers are cool with much fog and rain; the winters are not severe, but clear days are rare and snow falls to the depth of several feet. Among the neighboring mountains the snow-fall is excessive and occurs during every month of the year. In the névé region near Mt. St. Elias at an elevation of about 5,000 ft. it is not uncommon to see strata of compact snow without a parting, fifty feet thick exposed in the walls of crevasses. The mean annual temperature on the coast is thought to be about 40-45 deg. F., but this estimate is based on observation at a very limited number of stations. The humidity is excessive, and the mean annual rain-fall

is known to be about an hundred inches. In the vicinity of Mt. St. Elias it is probably even greater than this. The prevailing winds are from the south, at least in summer, and are laden with moisture which is precipitated when the mountains are reached. To the north of the mountains the climate is far different from what it is on the coast. The summers are short and hot and the winters marked by extreme severity; the rainfall is small throughout the year and perennial snow is not seen even on mountains four or five thousand feet high and situated near and even north of the Arctic Circle.

On the mountains facing the ocean the winter snow extends down to sea level but melts during spring and summer so as to form a well defined boundary, or "snow line," which recedes from the coast as the warm season advances. In August and September it has an elevation of about 2,500 feet, corresponding on the glaciers with the lower limit of the névés. The regions below and above the snow line are in marked contrast. From the ocean up to an elevation of from 2,500 to 3,000 feet in summer, every island in the ice as well as the low lands along the coast and even the moraines on the lower border of the Piedmont ice-sheet, are covered with luxuriant vegetation, and are frequently brilliant with banks of flowers. Above the snow line except on occasional sunny slopes at comparatively low elevation, where Alpine flowers thrive, all is desolate, lifeless winter. The well known features characteristic of glacial ice and névé snow are sharply defined by the same horizon. In the higher mountains snow storms are frequent even in summer, and at elevations exceeding about 13,000 feet rain never falls and the snow is fine and dry. On the mountain tops the snow does not soften, even on hot summer days. Its indefinite accumulation is prevented by avalanches and by its being blown away.

The relief of the St. Elias region is due largely to displacements. The mountains are in many instances formed of tilted blocks bounded by faults, and the prevailing structure approaches the Great Basin type. The effects of pre-glacial stream erosion are not distinguishable and in many instances the ice drainage is

consequent upon the prevailing structure. This is shown principally by the fact that large glaciers, such as the Agassiz and Seward, follow lines of displacement; in several instances, cascades occur where glaciers cross faults.

THE PIEDMONT ICE SHEET.[1]

Area.—The Malaspina glacier extends with unbroken continuity from Yakutat bay 70 miles westward, and has an average breadth of between 20 and 25 miles. Its area is approximately 1,500 square miles; or intermediate in extent between the area of the State of Rhode Island and the area of the State of Delaware.

It is a vast, nearly horizontal plateau of ice. The general elevation of its surface at a distance of five or six miles from its outer border is about 1,500 feet. The central portion is free from moraines or dirt of any kind, but is rough and broken by thousands and tens of thousands of crevasses. Its surface, when not concealed by moraines, is broadly undulating, and recalls the appearance of the rolling prairie lands west of the Mississippi. From the higher swells on its surface one may see for many miles in all directions without observing a single object to break the monotony of the frozen plain. So vast is the glacier that, on looking down on it from elevations of two or three thousand feet above its surface, its limits are beyond the reach of vision.

Lobes.—The glacier consists of three principal lobes, each of which is practically the expansion of a large tributary ice stream. The largest has an eastward flow, toward Yakutat bay, and is supplied mainly by the Seward glacier. The next lobe to the west, is the expanded terminus of the Agassiz glacier; its current is toward the southwest. The third great lobe lies between the Chaix and Robinson hills, and its main supply of ice is from the Tyndall and Guyot glaciers. Its central current is south-

[1] This account of the Malaspina glacier has been compiled principally from the proof-sheets of a report by the writer on a second expedition to Mt. St. Elias in 1891, to appear in the Thirteenth Ann. Rep. of the U. S. Geological Survey.

ward. The direction of flow in the several lobes explains the distribution of the moraines about their borders.

The Seward lobe melts away before reaching Yakutat bay and ends with a low frontal slope, but its southern margin has been eaten into by the ocean, so as to form the Sitkagi bluffs. The Agassiz lobe is complete, and is fringed all about its outer border by broad moraines. The Guyot lobe pushes boldly out into the ocean, and breaking off forms magnificent ice cliffs.

Characteristics of the non-moraine-covered surface.—On the north border of the glacier, but below the line of perpetual snow, where the great plateau of ice has a gentle slope, the surface melting gives origin to hundreds of rills and rivulets which course along in channels of clear ice until they meet a crevasse or moulin and plunge down into the body of the glacier to join the drainage beneath. On warm summer days when the sun is well above the horizon the murmur of streams may be heard wherever the ice surface is inclined and not greatly broken, but as soon as the shadows of evening cross the ice fields melting ceases and the silence is unbroken. These streams are always of clear, sparkling water, and it is seldom that their channels contain debris. Where the surface of the glacier is nearly level, and especially when broken by crevasses, surface streams are absent, although the clefts in the ice are frequently filled with water. The moulins in which the larger of the surface streams usually disappear are well-like holes of great depth. They are seldom straight, however, as the water in plunging into them usually strikes the opposite side and causes it to melt away more rapidly than the adjacent surfaces. The water in descending is dashed from side to side and increases their irregularities. A deep roar coming from the hidden chambers to which the moulins lead frequently tells that large bodies of water are rushing along the ice caves beneath. In the southern portion of the glacier, where the ice has been deeply melted, and especially where large crevasses occur, the abandoned tunnels made by englacial streams are sometimes revealed. These tunnels are frequently 10 or 15 feet high, and occasionally one may pass

through them from one depression in the glacier to another. In some instances they are floored with debris, some of which is partially rounded. As melting progresses this material is concentrated at the surface as a moraine.

The ice in the various portions of the glacier was observed to be formed of alternate blue and white bands, as is the rule in glacial ice generally. The blue bands are of compact ice, while the white bands are composed of ice filled with air cavities. The banded structure is usually nearly vertical, but the dip, when noticeable, is northward. Nearly parallel with the blue and white layers, but crossing them at low angles, there are frequently bands of hard, blue ice several hundred feet long and 2 or 3 inches in thickness which have a secondary origin, and are due to the freezing of waters in fissures.

The rapid melting of the surface produces many curious phenomena, which are not peculiar to this glacier, however, but common to many ice bodies below the line of perpetual snow. The long belts of stone and dirt forming the moraines protect the ice beneath from the action of the sun and air, while adjacent surfaces waste away. The result of this differential melting is that the moraines become elevated on ridges of ice. The forms of the ridges vary according to the amount and character of the debris resting upon them. In places they are steep and narrow, and perhaps 150 or 200 feet high. From a little distance they look like solid masses of debris, and resemble great railroad embankments, but on closer examination they are seen to be ridges of ice, covered with a thin sheet of earth and stones. The sides of such ridges are exceedingly difficult to climb, owing to the looseness of the stones, which slide from beneath one's feet and roll down the slopes. The larger bowlders are the first to be dislodged by the melting of the ice, and, rolling down the sides of the ridges, form a belt of coarse debris along their margins. In this way a marked assortment of the debris in reference to size and shape frequently takes place. In time the narrow belts of large bowlders become elevated in their turn and form the crests of secondary ridges. Rocks rolling down the steep slopes are

broken into finer and finer fragments and are reduced in part to the condition of sand and clay. When the debris is sufficiently comminuted it is sometimes carried away by surface streams and washed into crevasses and moulins. Not all of the turbidity of the subglacial streams can be charged to the grinding of the glacier over the rocks on which it rests, as a limited portion of it certainly comes from the crushing of the surface moraines during their frequent changes of position.

Isolated blocks of stone lying on the glacier, when of sufficient size not to be warmed through by the sun's heat in a single day, also protect the ice beneath and retain their position as the adjacent surface melts, so as to rest on pedestals frequently several feet high. These elevated blocks are usually flat, angular masses, sometimes 20 feet or more in diameter. Owing to the greater effect of the sun on the southern side of the columns which support them, the tables are frequently inclined southward, and ultimately slide off their pedestals in that direction. No sooner has a block fallen from its support, however, than the process is again initiated, and it is again left in relief as the adjacent surface melts. The many falls which the larger blocks receive in this manner cause them to become broken, thus illustrating another phase of the process of comminution to which surface moraines are subjected. On Malaspina glacier the formation of glacial tables is confined to the summer season. In winter the surface of the glacier is snow-covered and differential melting can not be marked. The fact that glacial tables are seldom seen just after the snows of winter disappear suggest that winter melting takes place to some extent, but in a different manner from what it does in the summer. Just how the blocks are dislodged from the pedestals in winter has not been observed.

While large objects lying on the surface of the glacier are elevated on pedestals in the manner just described, smaller ones, as is well known and especially those of dark color, become heated by the sun, and, melting the ice beneath, sink into it. When small stones and dirt are gathered in depressions on the surface of the glacier, or, on a large scale, when moulins

become filled with fine debris and the adjacent surface is lowered by melting, the material thus concentrated acts as do large bowlders, and protects the ice beneath. But as the gravel rises in reference to the adjacent surface, the outer portion rolls down from the pedestal on all sides, and the result is that a sharp cone of ice is formed, having a sheet of gravel and dirt over its surface. These sand cones, as they are called, sometimes attain a height of ten or twelve feet, and form conspicuous and characteristic features of the glaciers over large areas.

The surface of Malaspina glacier over many square miles, where free from moraine, is covered with a coral-like crust which results from the alternate melting and freezing of the surface. The crevasses in this portion of the vast plateau are seldom of large size, and, owing to the melting of their margins, are broad at the surface and contract rapidly downward. They are in fact mere gashes, sometimes ten or twenty feet deep, and are apparently the remnants of larger crevasses formed in the glaciers which flow down from the mountains. Deeper crevasses occur at certain localities about the border of the glacier, where the ice at the margin falls away from the main mass, but these are seldom conspicuous, as the ice in the region where they occur is always heavily covered with debris and the openings become filled with stones and bowlders. The generally level surface of the glacier and the absence of large crevasses indicate that the ground on which it rests is comparatively even. Where the larger of the tributary glaciers join it, however, ice falls occur, caused by steep descents in the ground beneath. These falls are just at the lower limit of perpetual snow and are only fully revealed when melting has reached its maximum and the snows of the winter have not yet begun to accumulate.

Moraines. — From any commanding station overlooking Malaspina glacier one sees that the great central area of clear, white ice is bordered on the south by a broad, dark band formed by bowlders and stones. Outside of this and forming a belt concentric with it is a forest-covered area, in many places four or five miles wide. The forest grows on the moraine, which rests

upon the ice of the glacier. In a general view by far the greater part of the surface of the glacier is seen to be formed of clear ice, but in crossing it one comes first to the forest and moraine-covered border, which, owing to the great obstacles it presents to travel, impresses one as being more extensive than it is in reality.

The moraines not only cover all of the outer border of the glacier, but stream off from the mountain spurs projecting into it on the north. As indicated on the accompanying map, one of these trains starting from a spur of the Samovar hills crosses the entire breadth of the glacier and joins the marginal moraine on its southern border. This long train of stones and bowlders is really a highly compound medial moraine formed at the junction of the expanded extremities of the Seward and Agassiz glaciers.

All of the glaciers which feed the great Piedmont ice-sheet are above the snow line, and the debris they carry only appears at the surface after the ice descends to the region where the annual waste is in excess of the annual supply. The stones and dirt previously contained in the glacier are then concentrated at the surface owing to the melting of the ice. This is the history of all of the moraines on the glacier. They are formed of the debris brought out of the mountains by the tributary Alpine glacier, and concentrated at the surface by reason of the melting of the ice.

Malaspina glacier in retreating has left irregular hillocks of coarse debris which are now densely forest-covered. These deposits do not form a continuous terminal moraine, however, but a series of irregular ridges and hills having a somewhat common trend. They indicate a slow general retreat without prolonged halts. The heaps of debris left as the ice front retreated have a general parallelism with the present margin of the glacier and are pitted with lake basins, but only their higher portions are exposed above the general sheet of sand and gravel spread out by streams draining the glacier.

The blocks of stone forming the moraines now resting on the

ice are of all sizes up to twenty or thirty feet in diameter, but those of large dimensions are not common. The stones are rough and angular except when composed of material like granite, which on weathering forms oval and rounded boulders of disintegration. So far as has been observed, very few of the stones on the glacier have polished or striated surfaces. The material of which the moraines are composed is of many kinds, but individual ridges frequently consist of fragments of the same variety of rock, the special kind in each case depending on the source of the thread in the great ice current which brought the fragments from the mountains.

In many instances, particularly near the outer border of the ice sheet, there are large quantities of tenacious clay, filled with angular stones, which is so soft, especially during heavy rains, that one may sink waist deep in the treacherous mass. Sometimes blocks of stone a foot or more square float on the liquid mud and lure the unwary traveler to disaster.

On the eastern margin of the ice sheet adjacent to Yakutat bay, where the frontal slope is low, there are broad deposits of sand and well rounded gravel which has been spread out over the ice. On the extreme margin of the glacier this deposit merges with hillocks and irregular knolls of the same kind of material, some of which rise a hundred feet above the nearest exposure of ice and are clothed with dense forests. The debris is so abundant and the ice ends in such a low slope that it is frequently impossible to determine where the glacier actually terminates. The water-worn material here referred to as resting on the glacier, has been brought out of tunnels in the ice, as will be noticed further on.

Surface of the fringing moraines.—A peculiar and interesting feature of the moraine on the stagnant border of Malaspina glacier is furnished by the lakelets that occur everywhere upon it. These are found in great numbers both in the forest-covered moraine and in the outer border of the barren moraine. They are usually rudely circular, and have steep walls of dirty ice which slope toward the water at high angles, but are undercut at the

bottom, so that the basins in vertical cross section have something of an hour-glass form. The walls are frequently from 50 to 100 feet high, with a slope of 40° to 50°, and sometimes are nearly perpendicular. Near the water's edge the banks are undercut so as to leave a ridge projecting over the water. The upper edge of the walls is formed of the sheet of debris which covers the glacier, and the melting of the ice beneath causes this material to roll and slide down the ice slopes and plunge into the waters below. The lakes are usually less than 100 feet in diameter, but larger ones are by no means uncommon, several being observed which were 150 or 200 yards across. Their waters are always turbid owing to the mud which is carried into them by small avalanches and by the rills that trickle from their sides. The rattle of stones falling into them is frequently heard while traveling over the glacier, and is especially noticeable on warm days, when the ice is melting rapidly, but is even more marked during heavy rains. The crater-like walls inclosing the lakes are seldom of uniform height, but frequently rise into pinnacles. Between the pinnacles there are occasionally low saddles, through which in some instances the lakes overflow. Frequently there are two low saddles nearly opposite to each other, which suggests that the lakes were formed by the widening of crevasses. The stones and dirt which fall into them, owing to the melting of the walls, gradually fill their bottoms. Instances are numerous where the waters have escaped through crevasses or openings in the bottom of the basin, leaving an exceedingly rough depression, with a heavy deposit of debris at the bottom.

As the general surface of the glacier is lowered by melting, the partially filled holes gradually disappear and their floors, owing to the deep accumulation of debris on them, which protects the ice from melting, become elevated above the surrounding surface, in the same manner that glacial tables are formed. The debris covering these elevations slides down their sides as melting progresses, and finally a rugged pyramid of ice, covered with a thin coating of debris, occupies the place of the

former lake. These pyramids frequently have a height of 60 or 80 feet, and are sometimes nearly conical in shape. They resemble "sand cones," but are of much greater size and are sheathed with coarser debris. The sand cones are usually, if not always, formed and melted away during a single season, while the debris pyramids require several seasons for their cycle of change.

Like the lakelets to which they owe their origin, the debris pyramids are confined to the stagnant portions of the glacier and play an important part in the breaking up and comminution of the material forming the marginal moraines. Owing to the sliding of the bowlders and stones into the lakelets and their subsequent fall from the sides of the pyramids, they are broken and crushed so that the outer portion of the glacier, where the process has been going on longest, is covered with finer debris and contains more clay and sand than the inner portions.

Just how the holes containing glacial lakelets originate it is difficult to say, but their formation seems to be initiated, as already suggested, by the melting back of the sides of crevasses. Breaks in the general sheet of debris covering the glacier expose the ice beneath to the action of the sun and rain, which causes it to melt and the crevasses to broaden. The openings become partially filled with water and lakelets are formed. The waves wash the debris from the ice about the margin of the lakelets, thus exposing it to the direct attack of the water, which melts it more rapidly than higher portions of the slopes are melted by the sun and rain. It is in this manner that the characteristic hourglass form of the basins originates. The lakelets are confined to the outer or stagnant portion of the glacier, for the reason that motion in the ice would produce crevasses through which the water would escape. Where glacial lakelets occur in great numbers it is evident that the ice must be nearly or quite stationary, otherwise the basins could not exist for a series of years. The lakelets and the pyramids resulting from them are the most characteristic features of the outer border of the glacier. The number of each must be many thousand. They occur not only in the outer portion of the barren moraine, but also throughout

the forest-covered area still nearer the outer margin of the glacier. Large quantities of trees and bushes fall into them with the debris that slides from their sides, and tree trunks, roots and soil, thus become buried in the moraines.

Forests on the moraines.—The outer and consequently older portions of the fringing moraines are covered with vegetation, which in places, particularly near the outer margin of the belt, has all the characteristics of old forests. It consists principally of spruce, alder and cottonwood trees, and a great variety of shrubs, bushes and ferns. In many places the ice beneath the dense forest is not less than a thousand feet thick. The vegetation is confined principally to the border of the Seward lobe. Near Yahtse river the belt is 5 miles broad, but decreases toward the east, and is absent at the Sitkagi bluffs, where the glacier is being eaten away by the sea. It is only on the stagnant borders of the ice sheet that forests occur. Both glacial lakelets and forests on the moraines are absent where the ice has motion. The forest-covered portion is by estimate between 20 and 25 square miles in area.

Outer margin.—The southern margin of Malaspina glacier, between the Yahtse and Point Manby, is abrupt and forms a bluff that varies in height from 140 to 300 feet or more. The bluff is so steep in most places and is so heavily incumbered with fallen trees and boulders, that it is with difficulty one can climb it. Many times the trouble in ascending is increased by land slides which have piled the superficial material in confused heaps, and in other instances the melting of the ice beneath the vegetation has left concealed pit-falls into which one may drop without warning. The bluff formed by the margin of the glacier when not washed by the sea, is boldest and steepest where the covering of vegetation is most dense. Where the covering consists of stones and dirt without vegetation, however, the margin may still be bold. This is illustrated between the mouth of the Yahtse and Icy cape, where the ice is concealed beneath a general sheet of debris, but has a bold convex margin which rises abruptly from the desolate torrent-swept waste at its base.

When the glacier meets the sea the ice is cut away at the water-level, and blocks fall from above, leaving perpendicular cliffs of clear ice. At Icy cape there is a bold headland of this nature from which bergs are continually falling with a thunderous roar that may be heard fully twenty miles away. On the crest of the cliffs of clear blue ice there is a dark band formed by the edge of the sheet of debris covering the glacier, and showing that the moraine which blackens its surface along its outer margin is entirely superficial. At Sitkagi bluffs the glacier is again washed by the sea but the base of the ice is there just above the water-level and recession is slow. The bluffs are heavily covered with stones and dirt, and icebergs do not form.

At the heads of the gorges in the margin of the glacier leading to the mouths of tunnels, the dirt-covered ice forms bold cliffs which are most precipitous at the heads of the reëntrant angles. The eastern margin of the ice sheet, facing Yakutat bay, is low and covered to a large extent with water-worn debris. The ridges on the glacier formed by moraines are there at right angles to the margin of the ice and are bare of vegetation. The reason for the exceptionally low slope of the eastern margin of the ice sheet seems to be that the current in the ice is there eastward and the glacier is melting back without leaving a stagnant border.

Marginal lakes. — The water bodies here referred to are called "marginal lakes" for the reason that they are peculiar to the margins of glaciers. Where rocks border an ice field or project through it they become heated, especially on southern exposures, and, radiating heat to the adjacent ice, cause it to melt. A depression is thus formed along the margin of the ice, which becomes a line of drainage. Water flowing through such a channel accelerates the melting of the ice, at least until a heavy coating of debris has accumulated. When a steep mountain spur projects into an ice field the lines of drainage on each side converge and frequently unite at its extremity, forming a lake, from which the water usually escapes through a tunnel in the ice. Typical instances of lakes of this character occur at Terrace point, at the

south end of the Hitchcock range, and again about the base of the Chaix hills.

When a stream flows along the side of a glacier a movement in the ice or the sliding of stone and dirt from its surface sometimes obstructs the drainage and causes the formation of another variety of marginal lakes. In such instances the imprisoned waters usually rise until they can find an outlet across the barrier and then cut a channel through it.

A glacier in flowing past the base of a mountain frequently obstructs the drainage of lateral valleys and causes lakes to form. These usually find outlets, as in the case of lakes at the end of mountain spurs, through a subglacial or englacial tunnel, and are filled or emptied according as the tunnel through which the waters escape affords free drainage or is obstructed. Several examples of this variety of marginal lakes occur on the west and north sides of the Chaix hills. They correspond in the mode of their formation with the well-known Merjelen See of Switzerland.

Other variations in the manner in which glaciers obstruct drainage might be enumerated, but those mentioned cover all of the examples thus far observed about Malaspina glacier. The conditions which lead to the formation of the marginal lakes are unstable, and the records which the lakes leave in the form of terraces, deltas, etc., are consequently irregular. When streams empty into one of these lakes, deltas and horizontally stratified lake beds are formed, as in ordinary water bodies, but as the lakes are subject to many fluctuations, the elevations at which the records are made are continually changing, and in instances like those about Malaspina glacier, where the retaining ice body is constantly diminishing, may occupy a wide vertical interval.

Drainage begins on the southeast side of Chaix hills at Moore's Nunatak, where during the time of our visit there were two small lakes, walled in on nearly all sides by the moraine covered ice of Malaspina glacier. The water filling these basins comes principally from the high ice fall at the north, where the glacier descends over a projecting spur running east from

Moore's Nunatak. The water escaped from the first lake across a confused mass of debris which had slid from the ice bluff bordering the stream and formed a temporary dam. Below the dam the water soon disappeared beneath deeply crevassed and heavily moraine-covered ice and came to light once more at the mouth of a tunnel about a mile to the southwest. The second lake, at the time of our visit, had almost disappeared, but its former extent was plainly marked by a barren sand flat many acres in extent, and by terraces along its western border. The lake occupied a small embayment in the hills, the outlet of which had been closed by the ice flowing past it. Below the second lake the stream flows along the base of densely wooded knolls and has a steep moraine-covered bluff of ice for its left bank. About a mile below it turns a sharp projection of rocks and cuts deeply into its left bank, which stands as an overhanging bluff of dirty ice over 100 feet high. The stream then flows nearly due west for some 3 miles to Crater lake. On its right bank is a terrace about 150 feet high which skirts the base of the Chaix hills and marks the position of the stream at a former stage. The terrace is about 100 yards broad, and above it are two other terraces on the mountain slope, one at an elevation of 50 feet and the other at 75 feet above the broad terrace. The upper terraces were only observed at one locality, and were probably due to deposits formed in a marginal lake at the end of a mountain spur.

The terraces left by streams flowing between a moraine-covered glacier and a precipitous mountain slope are peculiar and readily distinguishable from other similar topographic features. The channels become filled principally with debris which slides down the bank of ice. This material is angular and unassorted, but when it is brought within the reach of flowing waters soon becomes rounded and worn. On the margin of the channel, adjacent to the glacier, there is usually a heavy deposit of unassorted debris which rests partly upon the ice and forms the actual border of the stream. When the glacier is lowered by melting, the steam abandons its former channel and repeats

the process of terrace building at a lower level. The material forming the terrace at the base of Chaix hills is largely composed of blue clay filled with both angular and rounded stones and bowlders, but its elevated border is almost entirely of angular debris. The drainage from the mountain slope above the terrace is obstructed by the elevated border referred to, and swamps and lagoons have formed back of it. In the material forming the terraces there are many tree trunks, and growing upon its surface there is a forest of large spruce trees.

At the extreme southern end of the Chaix hills the drainage from the northeast, which we have been tracing, joins another stream from the northwest and forms Lake Castani. This lake, like the one at Terrace point, is at the south end of a precipitous mountain ridge projecting into the glacier and drains through a tunnel in the ice. The stream flowing from it is known as the Yahtse and flows for six or eight miles beneath the ice before emerging at its southern margin. Large quantities of both coarse and fine material are being carried into Lake Castani by tributary streams and is there deposited as deltas and lake beds. When the lake is drained, as sometimes happens, vast quantities of this material must be carried into the tunnel through which the waters escape.

On the west side of Chaix hills are several other marginal lakes of the same general character as those just described. The one next northwest of Lake Castani occupies a long narrow valley between two outstanding mountain ridges, and is retained by the glacier which blocks the end of the recess thus formed. This lake was clear of ice July, 1891, and of a dark blue color, showing that it received little drainage from the glacier. Other lakes on the northwest side of the Chaix hills are of a similar nature, and during my visit were heavily blocked with floating ice. On the north side of Chaix hills there are other small water bodies occupying embayments and retained by the glacier which flows past their entrances. The water from all these lakes escapes through tunnels.

The lakes to which attention has been directed are especially

interesting, as they illustrate one phase of deposition depending upon glaciation, and suggest that a great ice sheet like that which formerly covered New England very likely gave origin to marginal lakes, the records of which should be found on steep mountain slopes.

Drainage.—The drainage of the Malaspina glacier is essentially englacial or subglacial. There is no surface drainage excepting in a few localities, principally on its northern border, where there is a slight surface slope, but even in such places the streams are short and soon plunge into a crevasse or a moulin and join the drainage beneath.

On the lower portions of the Alpine glaciers, tributary to the main ice-sheet, there are sometimes small streams coursing along in ice channels, but these are short lived. On the borders of the tributary glaciers there are frequently important streams flowing between the ice and the adjacent mountain slope, but when these come down to the Malaspina glacier they flow into tunnels and are lost to view.

Along the southern margin of the glacier, between the Yahtse and Point Manby, there are hundreds of streams which pour out of the escarpment formed by the border of the glacier, or rise like great fountains from the gravel and bowlders accumulated at its base. All of these are brown and heavy with sediment and overloaded with bowlders and stones. The largest and most remarkable of these springs is the one indicated on the accompanying map as Fountain stream. This comes to the surface through a rudely circular opening, nearly 100 feet in diameter, surrounded in part by ice. Owing to the pressure to which the waters are subjected they boil up violently, and are thrown into the air to the height of 12 to 15 feet, and send jets of spray several feet higher. The waters are brown with sediment, and rush seaward with great rapidity, forming a roaring stream, fully 200 feet broad, which soon divides into many branches, and is spreading a sheet of gravel and sand right and left into the adjacent forest. Where Fountain stream rises, the face of the glacier is steep and covered with huge bowlders, many of which are too

large for the waters to move. The finer material has been washed away, however, and a slight recession in the face of the ice bluff has resulted. The largest stream draining the glacier is the Yahtse. This river, as already stated, rises in two principal branches at the base of the Chaix hills, and flowing through a tunnel some six or eight miles long, emerges at the border of the glacier as a swift brown flood fully one hundred feet across and fifteen or twenty feet deep. The stream, after its subglacial course, spreads out into many branches, and is building up an alluvial fan which has invaded and buried several hundred acres of forest.

In traversing the coast from the Yahtse to Yakutat bay, we crossed a large number of streams which drain the ice fields of the north, some of which were large enough to be classed as rivers. When the streams on flowing away from the glacier are large they divide into many branches, as do the Yahtse and Fountain, and enter the sea by several mouths. When the streams are small, however, they usually unite to form large rivers before entering the ocean. The Yahtse and Fountain, as we have seen, are examples of the first, while Manby and Yahna streams are examples of the second class. Manby stream rises in hundreds of small springs along the margin of the glacier which flow across a desolate torrent-swept area and unite just before reaching the ocean into one broad, swift flood of muddy water much too deep for one to wade.

On the border of the glacier facing Yakutat Bay, however, the drainage is different. The flow of the ice is there eastward, although the margin is probably stagnant, and instead of forming a bold, continuous escarpment, ends irregularly and with a low frontal slope. The principal streams on the eastern margin in 1891 were the Osar, Kame and Kwik. Each of these issues from a tunnel and flows for some distance between walls of ice. Of the three streams mentioned the most interesting is the Kame, which issues as a swift brown flood partially choked with broken ice, from the mouth of a tunnel and flows for half a mile in an open cut between precipitous walls of dirty ice 80 to 100

feet high. This is the longest open drainage channel that I have yet seen in the ice. It is about 50 feet broad where the stream rushes from the glacier, but soon widens to several times this breadth. Its bottom is covered with rounded gravel and sand, and along its sides are sand-flats and terraces of gravel resting upon ice. The swift, muddy current was dotted with small bergs stranded here and there in the center of the stream, showing that the water was shallow. Evidently the stream has a long subglacial course and carries with it large quantities of stones which are rounded as in ordinary rivers. Gravel and sand are being rapidly deposited in the ice channel through which it flows after emerging from its tunnel. Broad sand-flats are being spread out in the lakes and swamps two or three miles to the east. The stream is some four or five miles in length and near Yakutat bay meanders over a barren area perhaps a mile broad. I have called it Kame stream because of a ridge of gravel running parallel with it which was deposited during a former stage when the waters flowed about 100 feet higher than now and deposited a long ridge of gravel on the ice which has all the characteristics of the kames in New England. In the more definite classification of glacial sediments now adopted, this would more properly be called an osar.

Near the shore of Yakutat bay the streams from the glacier spread out in lagoons and sand-flats, where much of the finer portion of the material they carry is deposited. Sometimes this debris is spread out above the ice, and forms level terraces of fine sand and mud which become prominent as the glacier wastes away.

Osars.—The drainage of the glacier has not been investigated as fully as its importance demands, but the observations already made seem to warrant certain conclusions in reference to deposits made within the glacier by subglacial or englacial streams.

When the streams from the north reach the glacier they invariably flow into tunnels and disappear from view. The

entrances to the tunnels are frequently high arches, and the streams flowing into them carry along great quantities of gravel and sand. About the southern and eastern borders of the glacier, where the streams emerge, the arches of the tunnels are low, owing principally to the accumulation of debris which obstructs their discharge. In some instances, as at the head of Fountain stream, the accumulation of debris is so great that the water rises through a vertical shaft in order to reach the surface, and rushes upward under great pressure. The streams flowing from the glacier bring out large quantities of well rounded sand and gravel, much of which is immediately deposited in alluvial cones. This much of the work of subglacial streams is open to view and enables one to infer what takes place within the tunnels and to analyze to some extent the processes of subglacial deposition.

The streams issuing from the ice are overloaded, and, besides, on emerging, frequently receive large quantities of coarse debris from the adjacent moraine-covered ice cliffs. The streams at once deposit the coarser portion of their loads, thus building up their channels and obstructing the outlets of the tunnels. The blocking of the tunnels must cause the subglacial streams to lose force and deposit sand and gravel on the bottom of their channels ; this causes the water to flow at higher levels, and coming in contact with the roofs of the tunnels, enlarges them upwards ; this in turn gives room for additional deposits within the ice as the alluvial cones at the extremities of the tunnels grow in height. In this way narrow ridges of gravel and sand, having perhaps some stratification due to periodic variations in the volume of the streams, may be formed within the ice. When the glacier melts, the gravel ridges contained within it will be exposed at the surface, and as the supporting walls melt away, the gravel at the top of the ridge will tend to slide down so as to give the deposit a pseudo-anticlinal structure. Ridges of gravel deposited in tunnels beneath the moraine-covered portion of the Malaspina glacier, would have bowlders dropped upon them as the ice melts, but where the glacier is free

from surface debris there would be no angular material left upon the ridges when the ice finally disappeared. Such a system of deposition as is sketched above would result in the formation of narrow, winding ridges of cross-bedded sand and gravel, corresponding, seemingly, in every way to the osars of many glaciated regions. The process of subglacial deposition pertains especially to stagnant ice sheets of the Malaspina type, which are wasting away. In an advancing glacier it is evident that the conditions would be different, and subglacial erosion might take place instead of subglacial deposition.

Alluvial cones.—Below the outlets of the tunnels through which Malaspina glacier is drained, there are immense deposits of bowlders, gravel, sand, and mud which have the form of segments of low cones. These deposits are of the nature of the "alluvial cones," or "alluvial fans" so common at the bases of mountains in arid regions, and are also related to the "cones of dejection," deposited by torrents, and to the subaërial portion of the deltas of swift streams. As deposits of this nature have not been satisfactorily classified, I shall for the present call them "alluvial cones."

As stated in speaking of osars, the streams issuing from tunnels in Malaspina glacier at once begin to deposit. The larger bowlders and stones are first dropped, while gravel, sand and silt are carried farther and deposited in the order of their coarseness. The deposits originating in this way have a conical form, the apex of each cone being at the mouth of a tunnel. As the apexes of the cones are raised by the deposition of coarse material, their peripheries expand in all directions, and as the region is densely forest covered, great quantities of trees become buried beneath them. As the ice at the head of an alluvial cone recedes, the alluvial deposit follows it by deposition on the upstream side. The growth of the alluvial cones will continue so long as the glacier continues to retreat, or until the streams which flow over them have their subglacial courses changed. The material of the alluvial cones is as heterogeneous as the material forming the moraines on the border of the glacier, about which

they form, but the greater and practically the entire accumulation is more or less rounded and waterworn. Cross stratification characterizes the deposits throughout, and on the surface of many of the cones, and probably in their interior, also, there are large quantities of broken tree trunks and branches. The coarse deposits first laid down on a growing alluvial cone are buried beneath later deposits of finer material in such a way that a somewhat regular stratification may result. A deep section of one of these deposits should show a gradual change from fine material at the top to coarse stones and subangular bowlders at the bottom. Their outer borders are of fine sand and mud, and when the distance of the ocean is sufficient, the streams flowing from them deposit large quantities of silt on their flood plains. The very finest of the glacial mud is delivered to the ocean and discolors its water for many miles from land.

The formation of alluvial cones about the border of a stagnant ice sheet, and the deposition of ridges of gravel within it, have an intimate connection and are in fact but phases of a single process. The growth of an alluvial cone tends to obstruct the mouth of the tunnel through which its feeding stream discharges; this causes the stream to deposit within the tunnel; this, again, raises the stream and allows it to build its alluvial cone still higher. In the case of Malaspina glacier where this process has been observed, the ice sheet is stagnant, at least on its border, and is retreating. The ground on which it rests is low, but is thought to be slightly higher on the southern margin of the glacier than under its central portion. The best development of alluvial cones and osars would be expected in a stagnant ice sheet resting on a gently inclined surface, with high lands on the upper border from which abundant debris could be derived. These ideal conditions are nearly reached in the example described.

Glacial and ocean records.—Much has been written concerning the character of the deposits made by glaciers when they meet the ocean, but so far as can be judged from the conditions observed about the borders of Malaspina ice sheet, the sea

is much more powerful than the ice. Where the two unite their action, the sea leaves the more conspicuous records. The waters are active and aggressive, while the glacier is passive. Where the glacier enters the ocean its records are at once modified and to a great extent obliterated. The presence of large bowlders in marine sediments, or in gravels and sands along the coast is about all the evidence of glacial action that can be expected under the conditions referred to. Where the swift streams from the Malaspina glacier enter the ocean the supremacy of the waves, tides, and currents is even more marked. The streams are immediately turned aside by the accumulation of sand bars across their mouths, and nothing of the nature of stream-worn channels beneath the level of the ocean can exist. All of the deposits along the immediate shore between the Yahtse and Yakutat bay have the characteristic topographic features resulting from the action of waves and currents and do not even suggest the proximity of a great glacier.

Recent advance.—On the eastern margin of Malaspina glacier, about four miles north of Point Manby, there is a locality where the ice has recently advanced into the dense forest and cut scores of great spruce trees short off and piled them in confused heaps. After this advance the ice retreated, leaving the surface strewn with irregular heaps of bowlders and stones and inclosing many basins which, at the time of our visit, were full to the brim. The glacier during its advance plowed up a ridge of blue clay in front of it, thus revealing in a very satisfactory manner the character of the strata on which it rests. The clay is thickly charged with sea-shells of living species, proving that the glacier, during its former great advance, probably extended to the ocean, and that a rise of the land has subsequently occurred. This is in harmony with many other observations which show that the coast adjacent to Malaspina glacier is now rising. The blue color of the subglacial strata is in marked contrast with the browns and yellows of the moraines left on its surface by the retreating ice, which, in common with the fringing moraines still resting on the glacier, show considerable weather-

ing. Among the shells collected in the subglacial clay Dr. W. H. Dall has identified the following;

Cardium gronlandicum, Gronl.
Cardium islandicum, L.
Kennerlia grandis, Dall.
Leda fossa, Baird.
Macoma sabulosa, Spengler.

Similar shells, all of living species, were previously found at an elevation of five thousand feet on the crest of a fault scarp at Pinnacle pass, showing that recent elevations of land much greater than the one recorded in the marine clay just noticed have taken place. In fact there are several indications that the coast in the vicinity has been rising and that the same process is still continuing.

ISRAEL C. RUSSELL.

THE OSAR GRAVELS OF THE COAST OF MAINE.[1]

In the interior of Maine we find the long osars interrupted near the tops of transverse hills crossed by the glacial rivers, and still more interrupted on steep southern slopes. In such situations it is evident that the velocities of the osar rivers would be greater than the average, with the result that the rivers swept their channels clear of sediments. The conditions were those of transportation by the glacial rivers rather than deposition.

If we follow the osars southward toward the ocean we find at about the average distance of thirty miles from the shore that the osars begin to be interrupted in a different manner from that in the interior. Gaps begin to appear in the ridges in level ground where the land slopes could not cause an accelerated motion of the glacial rivers. Indeed, the gravels more often appear on the tops of low hills than in the lower grounds. Going southward the sizes of the ridges become on the average smaller, their materials rather coarser, the intervals longer, and finally near the northern ends of the bays or fjords of the coast they disappear. If they continue farther southward or into the sea, it is in masses that are so small as to be covered out of sight by the marine beds. The coastal towns are usually covered by clays, and road gravel is often in great demand. The vigilance of town officers has often detected beneath the marine clays small mounds of gravel that form the southern ends of gravel systems. To the south we reach a region where no gravels have been found. When we find an osar system graduating into mounds so small that not even the selectmen of a Maine town can find water-washed road gravel, we may be sure that our osar has come practically to an end. I have examined the charts of the Coast

[1] Condensation of chapters of a report on the Glacial Gravels of Maine, written for the U. S. Geological Survey.

Survey showing the sea bottom for a few miles off the coast. If there were any broad gravel hills 100 to 150 feet high, such as are found thirty miles north from the bays, they ought to be shown, and I do not find them. The charts often report gravelly bottom but it is uncertain whether this is till or glacial gravel. I find no evidence that these soundings showing gravel are connected with ridges of any considerable size. While then it is as yet impossible to know the geological significance of the gravel reported on the sea floor, yet in most cases the gravels end so evidently north of the shore that the interpretation is distinctly favored that none of the gravel systems reach far beneath the sea. No osar gravels have I been able to find on the islands situated south of the apparent ends of the gravel systems.

There are other significant peculiarities of the coastal gravels than those to be named in this paper, and many collateral or alternative questions and hypotheses had to be worked out. For the present we confine our attention to the three following characteristics :

1. The decrease in the average size of the glacial gravel masses as we go toward the coast till they often become cones not more than twenty or thirty feet in diameter and four or five feet high. In general, the marine clays are twenty feet or more in depth and would easily cover out of sight masses smaller than those above named.

2. The increasing discontinuity of the osar systems, the gaps between the successive ridges, massive mounds or plains, lenticular hills, domes, cones, and mounds increasing from a few rods up to two or three miles.

3. The practical ending of the osar gravels near the north ends of the fjords (fjord line). It is not meant to assert that there are absolutely no osar mounds beneath the sea or on the land south of the discovered gravels. But if any exist they are hidden by the marine beds, and are so insignificant in size as compared to the osar gravels found a few miles farther north that for all practical purposes we may assume that they end. If the osar mounds go on decreasing as fast southward as they do

within the last few miles of their traceable courses, they certainly must entirely disappear within three to five miles of their apparent endings. We omit here the overwash gravels that were deposited in front of the ice beneath the present ocean.

It is to be noted that these gravels are in lines or systems, and often toward the north pass into continuous osars. They are regarded as having been deposited by a single glacial river, that is, all that are classed as a single system. The intervals between the separated gravel masses are not due to erosion of a once continuous body. But the problem relates to the reasons why a single glacial river deposited sediments at intervals here and there within its channel.

In placing the problem before us, we have to consider the extent of the region in question. The above-named characteristics are associated with each other along two hundred miles of coast. Every few miles throughout this district we come to places where a glacial river has left its sediments. All these gravel systems exhibit the first two of the above named characteristics, and all but four or five, the last. Three osars end at the shore but near the north end of Penobscot bay several miles north of the general fjord line. Two others, perhaps the largest systems in the state, come down to the shore and the soundings seem to support the conclusion that they extend for a short distance under the sea. Horizontally, these changes mostly take place within a belt not far from thirty miles in breadth; vertically in most cases between sea level and the two hundred feet contour. The last named, the ending of the gravels, occurs between contours hardly fifty feet apart.

It is granted that the sea in late glacial time stood along the outer coast line, a little more than two hundred feet above its present level. In the interior its elevation was more than twice this height. All the beaches along the outer coast, whose height I have measured, have nearly the same elevation. In other words, the surface of the sea in late glacial time was substantially parallel to its present surface in the direction of the coast, though at a higher level.

In the coastal region we find numerous marine glacial deltas deposited in front of the ice by glacial rivers that flowed into the sea, but we do not find such frontal or overwash sediments as naturally form in front of glaciers terminating above sea level. These and other facts prove that the ice had not all melted over the coastal region before the advance of the sea. The subsidence of the land (apparent advance of the sea) either preceded the retreat of the ice over the coastal region or accompanied it in such a manner that all the land free from ice was covered by the sea as fast as the ice melted, up to the time when the sea had advanced northward to the highest beach. That is, up to this time, all the subglacial streams poured into the sea at the ice front and not on land above the sea. It follows that the causes of the ending of the osar systems north of the shore not only acted parallel to the present and former surface of the sea, but also in a region where the basal ice was bathed in sea water.

The presence of deep glacial pot-holes in considerable numbers near the coast proves the existence of subglacial streams in that region. Since there are no glacial gravels near these pot-holes, we have proof that there were rapid subglacial streams that left no gravels. Evidently their velocities were such that they transported all their sediments beyond our field (out into the region now under the sea). For years my conclusion has been that the osar rivers of the coastal region of Maine were all subglacial. Assuming the subglacial streams, the problem now resolves itself into this: How happened it that as the subglacial rivers approached the coast, they all found themselves able to sweep their channels free from sediments at nearly the same elevation?

Without here pausing to consider the genesis of the subglacial tunnels, we confine ourselves to the question, how are the tunnels enlarged? Two physical agencies do most of the work. First, mechanical erosion; second, melting of the ice walls by surface waters. In the case of ordinary mountain glaciers there is usually considerable land on the mountains that is bare of ice, and thus water warmed on the land passes beneath the ice and

helps to enlarge the subglacial or englacial channels. But, in the case of ice sheets covering all the land, the only heat available for enlarging the tunnels (omitting the small amount of basal heat) is the heat absorbed by surface waters and carried by them beneath the ice. It is known that the waters of surface melting often collect in superficial brooks and torrents of considerable size. The absorption of radiant energy from the sunlight is instantaneous, or at least much more rapid than the conduction of this energy as molecular heat from the water to the ice with which it is in contact. Under sunlight all surface waters become warmed a little above 32°, and, as they plunge beneath the ice, they give up their surplus heat to help melt the walls of the subglacial channels. This, I infer, is the most efficient of all the agencies that help to enlarge the subglacial tunnels. Enlargement of the subglacial tunnels is not uniform. Thus, where a surface stream pours beneath the ice and brings a fresh supply of heat into the tunnel, there would be more rapid enlargement than elsewhere. For various reasons, not necessary to be discussed here, the enlargement of the tunnels proceeds unequally.

Given a tunnel gradually enlarging till sedimentation begins, this sedimentation will commence at the most favorable places, as at the local enlargements, or at an obstruction. If, now, the size of the tunnel, or rather the ratio between the tunnel capacity and amount of water increase, sedimentation will take place at more frequent intervals, and if the tunnel becomes large and rather uniform in size, the sediments will form a continuous ridge.

Various causes can be adduced why a glacial stream should deposit a diminishing quantity of sediment, but the controlling cause and almost the only one admissible under the peculiar local circumstances is the following: We grant that as we go southward toward the distal extremity of the glacier the supply of drainage water will increase, as in all drainage systems. But all these surface waters take with them heat as they pass beneath the ice to help enlarge the tunnels. Thus, as it were, each

region of the glacier furnishes the heat to enlarge the tunnels within its own limits. This is the natural career of ordinary ice sheets above the sea.

An important law of the enlargement of subglacial tunnels depends on the velocity of ice movement. Subterranean waters, as those of the limestone caves, go on enlarging their channels from age to age, because they act continuously on the same body of rock. But the subglacial tunnel cannot become thus enlarged, because of the constant renewal of the ice. Other things being equal, the enlargement of the subglacial tunnels is directly proportional to the time during which it is being enlarged, and inversely as the rate of ice flow. Obviously, when the flow is rapid the tunnel never becomes very much enlarged, for before this can happen the ice at any given part of the channel is pushed on to the distal extremity and disappears by melting or by berg discharge.

The details, here omitted, prove there was probably a small acceleration of the rate of ice flow as the coast of Maine was approached, hence the rate of enlargement of the ice channels would not increase so rapidly as the supply of water of local melting. But the surface of that region is much diversified with hills and valleys. The rate of ice flow would be most rapid in the deeper north and south valleys, and would be retarded in the lee of the higher transverse hills, of which there are several long systems. If differences in the rate of ice flow were the only cause of different rates of ice channel enlargement, then we ought, on such an uneven coast, to find evidence of the fact in the distribution of the gravels. Examination shows that this was a real cause of varying rates of enlargement, but it was a minor cause. This cause alone could not have enabled all the subglacial rivers to clear their tunnels of sediments at the same or nearly the same horizontal line. It would have acted at various levels, according to the conditions for rapid ice supply from the north.

We have seen that the ice in late glacial time flowed into the sea in the coastal region of Maine. It remains for us to inquire

what is the effect of the flowing of a glacier down into a body of water upon the enlargement of the subglacial tunnels. In such a case the tunnels and all crevasses opening into them are permanently filled with water up to the level of the surface of this body of water. But it is by the crevasses that the waters of local melting get down into the subglacial tunnel. The permanent water in the crevasses is at the temperature of 32°. As the waters of surface melting in the region whose basal ice is submerged in the sea or other body of water pour into the crevasses they cannot at once fall to the ground and enter the tunnels, but they fall into the water in the crevasses that already fills them to the level of the permanent body of water. The large streams find their way pretty directly into the tunnels, but all the smaller streams and trickles become so mixed with the cold waters in the crevasses that their heat, instead of being consumed in enlarging the tunnels, is largely expended in melting the ice walls of the crevasses above the level of the tops of the roofs of the tunnels.

Thus the flowing of a glacier down into the sea interferes with the natural transfer of heat beneath the ice whereby the tunnels are enlarged in large part. But the supply of surface waters is the same over the area whose base is submerged as elsewhere. The conclusion follows, that as we go toward the distal extremity of a glacier that flows into a body of water, the supply of drainage waters would be increased more rapidly than the tunnel capacity. This would result in increased velocity of the rivers, with a corresponding increase in power of transportation. In other words, they would do just as the osar rivers of Maine did as they approached the coast—would deposit sediments at longer and longer intervals, and in smaller quantities, and finally would sweep their tunnels free from all sediments.

Now it is certain and inevitable that the submergence of the basal ice should restrict the enlargement of the subglacial tunnels, yet it is an open question whether this was sufficient to account for the peculiar development of the coastal gravels.

We have seen that these changes take place within a belt not

far from thirty miles wide. Without assuming any definite rate or rates of ice movement we can at least all agree that it would take many years for the ice to advance such a distance. An obstruction to the natural transfer of heat beneath the ice, and consequent enlargement of the tunnels, though it might be slow in its action, would, after a term of years, have a cumulative effect on the development of the tunnels, at least in cases where the subglacial rivers flowed in channels parallel with the ice flow.

We have seen that the three features of the coastal gravels above stated are associated together over a wide area, and would appear to have a common origin. Glacial rivers of different lengths, from five up to more than one hundred miles, all show the same development. At almost the same elevation they all were able to sweep their tunnels clear of sediments. We must seek for some cause capable of acting along two hundred miles of coast in lines approximately parallel to the surface of the sea. What but the sea itself could do this under so many varying topographical and glacial conditions?

Rightly interpreted, it would appear that the termination of the gravel systems north of the shore line is itself a proof of the former elevation of the sea. We may leave it as an open question how far the sea acted in other ways—such as by diminishing the effective "head" of the subglacial streams, etc., but that the sea was chiefly responsible for the peculiar development of the coastal gravels, I am persuaded, is the best interpretation of the facts. And of all the ways in which the sea or other body of water that submerges the base of a glacier affects the subglacial streams and their tunnels, I have been able to discover none so potent as that which is above described, whereby the enlargement of the tunnels is obstructed.

Where subglacial rivers flowed up and over transverse hills, as they often did in Maine, there would be a body of slack water in the tunnels, like a sewer trap, on the north sides of the hills. Some of these bodies of slack water or dams on the north sides of hills were from five to ten or fifteen miles long, and in one

extreme case about twenty miles. The ice would be so long passing over such distances that we could expect that the basal water would restrict the enlargement of the tunnels sufficiently to show a characteristic development of the gravels, such as narrowness of the osars or gaps without gravels. While in such situations I nowhere find so extreme a development as in the coastal region, yet there are numerous facts that are best interpreted by the hypothesis that the basal waters of the slack water dams in the subglacial tunnels did somewhat obstruct the enlargement of the tunnels; and thus far I have found none inconsistent with that hypothesis.

The critical reader will have noted that the belt of transition of the coastal gravels of Maine is approximately parallel to the ice front at one stage of the retreat of the ice. It is also somewhat parallel to the southern margin of the *névé*. It has been necessary to consider whether the coastal gravels were retreatal phenomena, connected with some late stage of the ice sheet's history, also what effect would be produced by the retreat northward of the *névé* line, whether the discontinuous gravels were due to the gradual rise of the sea, etc. The result has been to relegate all the suggested agencies to a subordinate position with respect to the two causes above named—a probable small acceleration of ice flow near the coast and the limited enlargement of the subglacial tunnels over the area whose basal ice was submerged in the sea.

GEORGE H. STONE.

THE HORIZON OF DRUMLIN, OSAR AND KAME FORMATION.

In an article in the first number of this journal on the nature of the englacial drift of the Mississippi basin, I endeavored to show by evidence drawn from a wide area of the interior that erratics dislodged from the summits of the hills of crystalline rock in the northern region by the Pleistocene ice-sheet were borne south within the ice in such a way as to be kept separate from the basal material throughout the whole course of their transportation, and that they were at length let down upon the surface of the basal drift at the margin of the ice as a separate deposit. The evidence seemed to force the view that the basal material was not carried upward by transverse ice currents even into the heart of the glacier much less to its surface. The facts there cited seemed to make it clear that there is not only a theoretical but a practical horizon of demarcation between the englacial drift and the basal drift, and that under circumstances of this kind—and they seem to have wide prevalence—there is little or no confusion of the two. Very possibly this conclusion does not hold equally good in very hilly or mountainous regions.

In carrying out into further application this distinction, it seems well to specify the precise sense in which the term englacial is used. It may be applied to any erratic material that, at any time during its transportation, may be enclosed within the ice even though it be essentially at the bottom of the glacier and may have been actually at the bottom a little before and may again be at the base a little later on; or it may be applied, less technically but more significantly, to that only which is embedded in the heart of the ice and borne passively along with it free from basal influences until it is at length brought out to the surface of the terminal slope by the agency of ablation.

It is clear that all erratic material as it was brought to the front edge of the ice appeared either on the surface or at the base. There is here a sharp physical horizon of demarcation. If the material that had been basal some distance back from the edge was carried up to the surface, or carried up so far into the body of the ice that the surface was brought down to it by ablation near the border, it is evident that it must have become commingled with that which had been englacial or superglacial from the moment it was dislodged from its parent hills, and hence this horizon of demarcation would not distinguish between the two classes of material as such. The distinction would rest upon mode of transportation and deposition. But if the interpretation of the article referred to is correct and holds good generally in similar regions, the horizon becomes a plane of separation between the classes of material as well, and assumes much importance in practical glaciology. It was, however, obviously not an absolute plane of demarcation, even at the border of the ice, and when we attempt to apply it to sections lying farther back, it needs some qualification.

Without doubt material which was picked up by the ice along its base was thrust up into it to greater or less heights. As a particular instance, beds of rock which were inclined upward toward the oncoming ice were obviously disposed to thrust themselves into it as they were being tilted out of their positions. They appear to have rotated upon their lower edges, as upon a hinge, and were probably only removed from their places after they had been turned into a vertical position or perhaps somewhat beyond it. They were then almost wholly embedded in the ice, and so, in a limited sense, they were englacial. So also it is extremely probable that, in the case of undercut ledges, sharp ravines, narrow gorges, and similar very abrupt inequalities in which the surface was suddenly depressed, there was more or less overriding of the basal currents of the ice and consequent incorporation or overplacement of the material held in the bottom of the overrunning portion. But notwithstanding the fact that this material became englacial in a limited sense, because

it was not absolutely at the bottom of the ice, I think, in a genetic view, it is to be regarded as basal unless it was lifted so high into the body of the glacier as to be borne onward thenceforth entirely within the body of the ice and free from basal influences so that it was at length carried out to the surface as it approached the terminal edge, and was deposited as superglacial material. If the material remained approximately at the bottom of the glacier and again descended to the absolute base of the ice, it seems to me best to regard it as basal, even though it may be, for a time, completely enveloped within the ice. This seems best, because it represents the significant factor in the operation. In origin, it was basal, and, in the end, it became basal. It was only englacial by accident, temporarily.

Opposed to the agencies that tended to carry material from the absolute bottom of the ice into its basal portion to limited heights, there were several agencies that tended to bring it back to the absolute bottom. (1) The conduction of internal heat contributed slightly to this by melting away the base of the ice. The annual amount was undoubtedly very small, but the cumulative effects upon the bottom of any particular column of ice during the last five hundred miles of its journey (and this much is involved in certain aspects of the problem) was probably very appreciable and was manifestly greater in proportion to the slowness of the ice movement. (2) Basal friction undoubtedly gave rise to a much larger wastage and so lowered the embedded debris. (3) The introduction of warm waters from the surface, through the agency of crevasses, also caused wastage of the bottom, but this was obviously limited to such portions as were accessible to these waters and the effects were unequally distributed, although the positions of the streams undoubtedly changed from time to time, and this tended to spread the effects more generally over the bottom. (4) It is probable that there was a certain amount of penetration of solar rays through the ice. As the surface of a glacier is usually granular, only a minor portion of the sun's rays probably succeeded in penetrating to the transparent ice below. But such portions as reached this

were competent to traverse very considerable depths of ice without being entirely absorbed, being chiefly waves of short vibration. Those who have been beneath glaciers have observed that the amount of transmitted light is not inconsiderable. The transmitted rays of short vibration, so far as they reached the bottom, were arrested and, by transformation to rays of longer vibration, brought to bear upon the base of the glacier. The basal wastage from this source may be presumed to have increased somewhat in proportion as the ice thinned towards its margin, but this would be offset to some degree by a probable increase of surface detritus that would cut off the rays. The combined effect of these agencies would appear to have been not inconsiderable.

(5) In any vertical section of a glacier the lagging of the basal portion causes the plane of the section to lean forward, which means that each part is brought nearer to the bottom, carrying with it whatever material is enclosed. This being a general phenomenon justifies the conclusion that the tendency of the ice of the interior of a glacier is to flow obliquely forward and downward. Exceptions to this may be found when the resistance of a given portion of the base is greater than that of the portion immediately in its rear, in which case the latter may tend to flow over the former, but this will be reversed when the ratio of resistance is changed and would be, at most, but a variation of action, not a general law of action.

The combined effect of all these agencies was, if I reason correctly, to bring back to the base of the ice any material that owing to the special causes named, or to others, had been forced up into the lower parts of the ice. They tended to preserve the basal character of whatever had once become basal. And this seems to be supported by observations on existing glaciers.

These considerations have a very specific bearing upon the horizon at which drumlins, osars (eskers), and kames were formed. These all contain large quantities of local material, of basal derivation. If the view here stated is correct, these must be very strictly basal deposits, in general. There are doubtless

some qualifications and exceptions. This conclusion is not at all new, for, as is well known, it has been reached by several students of these phenomena quite independently. But an approach to the question along the line of evidence presented by *bowlder belts* and *bowlder trains* has its own advantages. It bears particularly upon a new view of the origin of drumlins recently advanced by one of our most experienced glacialists in which they are held to have been chiefly formed from englacial drift which "had become superglacial by ablation and was afterwards enclosed as a stratum within the ice-sheet, being thence amassed in these hills."[1]

In the midst of the drumlin area of south-central Wisconsin, there arise from beneath the Paleozoic strata a few scattered knobs of quartzite and quartz-porphyry from which erratics have been derived and borne away to varying distances, constituting bowlder trains of the most definite type. These are radically different from the bowlder *belts* discussed in my previous paper. The quartzite outcrops near Waterloo, in Jefferson County, are the most favorably situated for the purposes of the present study, because they are right in the heart of the most pronounced drumlin area and have made large contributions to the erratic content of the drumlins themselves. My associate, Mr. I. M. Buell, has been engaged for some time in a very careful study of the abrasion which these quartzite outcrops suffered from glaciation and of the distribution and special relationships of the erratic material derived from them. The drift movement was here to the south-southwestward and quartzite blocks derived from these outcrops enter in great abundance into the constitution of the drumlins lying in that direction. Several features of their distribution and nature are worthy of special note.

1. The quartzite bowlders are not simply scattered over the surface of the drumlins, but are distributed throughout their entire mass so far as accessible to observation. As the drumlins bear evidence of gradual accretion, it seems necessary to suppose that they were built up by successive additions of material

[1] "Conditions of Accumulation of Drumlins," Warren Upham, *American Geologist*, December, 1892. pp. 339–362.

derived from a stream of drift passing over the quartzite ledges and making constant additions from them.

2. The drumlins are found to be filled with quartzite erratics immediately in the lee of the ledges. There are even drumlins which lie directly upon the ledges and envelop them in large part, which are found free from local quartzite derivatives on their stoss ends, but are inset with them in their lee ends. The quartzite content of the leeward portion ranges, in observed sections, from 5 per cent. to 10 per cent. of the whole drift. In one case, Mr. Buell found an isolated drumlin to contain all of the quartzite of its particular kind observed in the vicinity. It evidently completely envelops the parent ledge and retains the most of its derivatives. Several bowldery mounds, that may be regarded as drumlins in miniature, occur in the immediate lee of the ledges, in which the quartzite drift was estimated to comprise from 20 per cent. to 75 per cent. of the whole. The material, in these instances, appeared to be chiefly former talus of the quartzite outcrops. Setting in thus promptly immediately at the quartzite outcrops, the erratics are found to diminish very markedly in proportion as the distance increases. A mile and a half away from the outcrops, a careful estimate of the quartzite content gave 3 per cent. of the whole mass of the drift. The average for the area between 1 and 6 miles is 1-1½ per cent.; between that and 20 miles 1 per cent.; between that and 45 miles .364 per cent., and in the terminal moraine .0477 per cent. The surface distribution shows a similar diminution. The estimated amount of quartzite on the very bowldery mounds near the ledges was 17,700 cords; at other points within six miles of the outcrops 12,650 cords; at medial points 1,409 cords; on the terminal moraine, about 45 miles distant, 747 cords. This very rapid diminution in the quantity of quartzite erratics is significant in showing that the element of resistance to transportation was an influential factor. This is precisely what is to be anticipated on the hypothesis that these bowlders were pushed or dragged along the base of the ice. It seems very far from what is to be expected, however, on the

hypothesis that the erratics rose in the ice and were transported englacially in any considerable degree. In this case, the greatest accumulation should have been at the terminal moraine where the ice halted longest. It seems to be also difficult to understand, on the hypothesis offered by Mr. Upham, how the drumlins lying immediately on the ledges and immediately in their lee could have been filled so largely with quartzite bowlders. Certainly the bowlders could not have risen in the ice so high as to have become exposed at its surface by ablation and then have been overflowed by a new accession of ice and moulded into the drumlin form, and at length have been let down by the melting of the ice beneath without more forward movement than observation shows. The simplicity of the facts do not seem to tally with the complexity of this theory.

3. The amount of abrasion which the bowlders suffered bears specifically upon the question of the mode of their transportation. The parent outcrops gave rise to erratics of three kinds. (1) In Paleozoic times the ledges stood as islands in the seas, and there accumulated about them very coarse conglomerates of quartzite. From these, a portion of the erratics were derived in an already rounded condition. The character of this rounding and the superficial changes the pebbles underwent before the glacial period made it possible for Mr. Buell to distinguish these with measureable certainty in following the train until abrasion had destroyed their surface characters. (2) Talus blocks accumulated about the bases of outcrops before the ice invasion that formed the drumlins. There was an earlier invasion which bore quartzite erratics westward. The later invasion bore them southwestward. The talus blocks under consideration are, perhaps, in the main, those that were derived from the quartzite knobs in the interval between the two. They are distinguishable from blocks disrupted by the ice by means of the weathered character of their several surfaces, so long as these remain unabraded. (3) The third class of erratics are those that were derived by direct action of the ice upon the parent knobs. These are distinguished by their unweathered fracture surfaces.

Among five hundred bowlders examined by Mr. Buell at two railroad sections, distant less than three miles from the most remote of the parent ledges, only ten were noted that did not plainly show by rounded edges and blunted angles the effects of glacial attrition. At a point less than twelve miles distant, the abrasion had so far obliterated the surface characters that it was hardly possible to determine to which of the three classes above indicated the erratics had originally belonged. Farther on, the evidences of abrasion are still more marked. The degree of abrasion did not appear to be equally great in the case of some of the bowlders found on the crest of some of the high ridges and on the surface of the terminal moraine. Mr. Buell's observations were made with the hypothesis of englacial transportation in mind as an accepted working hypothesis, but with only meagre results in the drumlin area. Studies at two points on the slope of the outer ridge of the terminal moraine and on the edge of the overwash plain gave fifty-six bowlders that were only slightly affected by glacial abrasion and eighty-eight which showed by their rounded forms and scratched surfaces the effects of severe glacial reduction. While therefore the observations do not exclude the hypothesis of a small amount of englacial transportation, if slight abrasion be taken as sufficient evidence of this, they limit it to a quite trivial factor of the whole mass.

The combined testimony of the foregoing facts seems to me quite decisive in its bearing on the proposition that the derivation, transportation and deposit of the quartzite bowlders was almost exclusively subglacial or at least closely basal. As these bowlders enter into the structure of the drumlins from base to summit, and are mingled with much other local material, the foreign element being relatively small, they seem to compel the same conclusion respecting the whole of the material which was built into the drumlin forms.

Mr. Buell has found what he regards as satisfactory evidence that an older train of bowlders was carried directly westward at the time of the earlier drift and that the later ice movement toward the southwest crossed this train obliquely and distributed

it over a much greater area than it originally occupied, forming a secondary train. The erratics of this secondary train, he finds much smaller in general and marked by greater evidence of glacial reduction than those of the unmodified later train. This has a double bearing upon the question of the origin of the drumlins in that it indicates basal transportation in both epochs and in that it indicates a direct accumulation of the drumlins *de novo* during the later incursion. It seems to exclude the view that the drumlins are remnants of the older drift; for, since the older train was westerly, there would be no quartzite material in the old drift lying southwesterly from the outcrops, and hence none would appear within the body of the drift in that region when worn into drumlin forms. But it is just here that quartzite erratics appear in their greatest abundance and permeate the body of the drumlins most impartially. The direct south-southwesterly bowlder train is so predominant that the older, and now more scattered, westerly one was not recognized by the earlier observers.

The testimony of these *bowlder trains* (basal phenomena distributed along the line of drift movement) combined with that of the *border belts* (superficial phenomena distributed transversely to the drift movement and parallel to the edge of the ice) seems therefore to add some special weight to the already familiar evidence supporting the view that drumlins are strictly basal aggregations.

There are no well defined osars (eskers) in this drumlin region, but there are tracts of gravelly knolls and ridges some of which seem to represent longitudinal glacial drainage lines, and so, genetically speaking, to stand for the esker phenomena. Aggregates of the kame type, or of an unclassifiable type of this general order, occur not infrequently among the drumlins. In connection with the moraines bordering the district, kames of the typical variety have an abundant development. Into all these, so far as they lie within the area of quartzite distribution, the quartzitic material enters in even greater abundance than into the average unmodified till of the drumlins themselves or

of the moraine. The mean of several observations upon kame-like accumulations of gravel lying within ten miles of the parent outcrops gave Mr. Buell 5 per cent. of quartzite, in the interior material accessible in sectional exposures. At points about midway between the parent ledges and the terminal moraine, forty-five miles distant, the average amount was found to be 1.2 per cent. Measurements made nearer the limit of the later drift showed .39 per cent., while on the margin, the quantities were usually found too small to be estimated in percentages.

It thus appears that the law of distribution found in the drumlins holds good for the kames save that the relative percentage of quartzite in the latter is greater than in the former; a fact which finds its explanation, in part certainly, in the fact that the clayey and other fine material of the drumlins enters into the estimate of percentage for them while it does not in the case of the kames, it having been chiefly washed away; and perhaps also, in part, in the fact of greater resistance to wear on the part of the quartzite.

These kame-like accumulations sometimes lie in the lee of the drumlins and form a part of the common hill or ridge, their contours blending into the common contours of the drumloid form, so that there can be no doubt that the two portions were simultaneous in formation, and that the horizon and environment of their accumulation were identical. In other instances, they are associated with cols or with valleys among the drumlins in such a way as to leave no doubt that the kames and drumlins were closely associated and essentially contemporaneous in formation. As some of these kame-like forms lie very near the parent quartzite ledges, it seems quite impossible to suppose that the quartzite erratics were borne to the surface by internal cross movement of the ice, and afterwards let down so near to the origin of the material as we find them. There seems, therefore, no escape from the conclusion that these are also very strictly basal phenomena, being but assorted and re-aggregated portions of the common drift of the drumlins and the general ground moraine.

Returning to the region of the superficial bowlder *belts* in Illinois, Indiana, and Ohio, we find hillocks of the kame type distributed throughout the same tracts as the bowlders, indeed, practically lying beneath the bowlder belts themselves. Some of these I described nine years ago in the American Journal of Science in an article entitled "Hillocks of Angular Gravel and Disturbed Stratification."[1] Additional evidence of the same import has been since gathered. Among the materials of these kame-like aggregates, it is not uncommon to find a complete series of gradational forms, ranging from incorporated masses or tongues of typical till of the ground-moraine type, through partially modified masses and layers of half-till, half-gravel, to completely assorted and stratified material, thus showing every stage of the derivation from the common underlying and surrounding till. The attrition of the material shows a like gradation. In some portions the clayey constituents of the till have been simply washed out leaving the rock fragments which show almost no perceptible wear from water. In others, the rounding has been more considerable, and in still others, there has been a reduction to the common rounded gravelly type. Even this is not usually well rounded. The less modified fragments not uncommonly show glacial striation. All these variations occur within the limits of a single hillock, and are often so intimately associated as to compel the conviction that the gravel is but a partially assorted derivative from the till of the region. In some of these hills the stratification is disturbed, not as though the beds had been let down by the removal of ice below, but as though they had been pushed horizontally by glacial pressure. The essentially local derivation of the material is demonstrated by the very notable presence of rock fragments derived from the formations of the neighborhood. More than half the material is not infrequently made up of limestone whose origin must be much nearer at hand than that of the superficial bowlder belt. An analysis representative of the gravel and sand of one of these kames gave as much as 70 per cent. magnesian limestone.

[1] Am. Jour. Sci., vol. XXVII, May 1884. Pages 378–390.

It is probably safe to say that in selected instances at least 90 per cent. of the material was derived from the Paleozoic series and more than half of this from the vicinity. This is, however, too large an estimate for the average, but the local constituents were never seen to be other than pronounced if not predominant. Material of local derivation also enters into the constitution of the sand and clay as well as the coarser material showing that the hillocks are made up not only of the glacially ground rock-fragments, but of the glacial grindings. The whole aspect of the material of these kames is so strikingly in contrast with that of the superficial bowlder belt and points so definitely to their derivation from the common sheet of subglacial till as to seem to put beyond doubt the view that they are quite strictly basal in formation.

Osars of the typical variety have comparatively few representatives in the plain tracts of the interior, but several well characterized instances occur. It is notable that, in most of these instances, as pointed out by Mr. Leverett, who has perhaps carefully studied a larger number of them than anyone else, they often lie in river-like channels cut into the till sheet of the region. There are perhaps a dozen of these that have been studied, varying in length from a few miles to about fifty miles. These channels have the characteristics of river troughs, and usually stand so related to the margin of the ice as to seem to indicate that they were lines of subglacial drainage during the same glacial stage as that in which the osars were formed. These channels are so related to the surface slopes that they could not have been formed by free open-air streams. The restraining aid of ice seems necessary. While no demonstration of the history of their formation can be claimed, the most plausible explanation appears to be that the river-like channels were cut by subglacial streams at a time when the urgency of the ice was such as to compel basal cutting, and that, subsequently, when the pressure of the ice was less insistent, and its motion feebler, the draining stream was permitted to fix its channel in a tunnel cut in the under surface of the ice, which

otherwise occupied the channel previously cut, and that the stream gradually built up its gravels within the tunnel so formed, essentially as indicated by Professor Russell in the case of tunnels under the Malaspina glacier. While the inferences drawn from this peculiar association of the osar ridges with river-like channels cannot be urged with the same force as the preceding considerations, they seem to support them in some degree. The constitution of these osar ridges is of the same local character as that of the kames above discussed except that perhaps it is less narrowly local and less intimately related to the underlying formations. The difference, however, is not marked.

From the foregoing evidences, the inference is drawn that the osars and kames of the plain region of the interior are basal phenomena in a degree almost as complete as the drumlins or the ground moraine. Inferences from such evidences as have been cited cannot, however, be applied with so much rigor in the case of osars and kames as in the case of drumlins, for the subglacial streams, that are held to have formed them, cannot be assumed to have always pursued strictly basal courses. Conditions may be supposed to have arisen which would have forced the streams into channels above the base of the ice, or even up over the ice in the thin marginal portion, so that accumulations may have taken place that were less strictly basal than those of the drumlins, and it is of course possible that kames and osars may have been formed, in particular instances, out of the englacial and superglacial material of the ice; but, following what seems to me the legitimate teachings of the foregoing lines of evidence and of observation, there seems warrant for concluding that such instances, though theoretically possible, are practically rare. I beg that it may be observed that these conclusions are drawn from the phenomena of the plain region of the interior and are applied to it, with the full recognition of the possibility that in hilly and mountainous regions modifications of the conclusions may be necessary.

T. C. CHAMBERLIN.

A CONTACT BETWEEN THE LOWER HURONIAN AND THE UNDERLYING GRANITE IN THE REPUBLIC TROUGH, NEAR REPUBLIC, MICHIGAN.

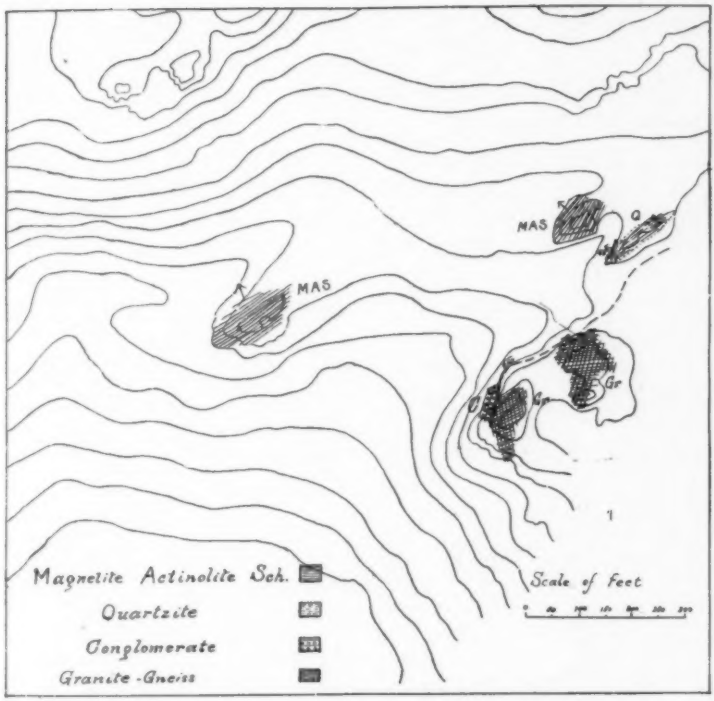
I.

THE lowest member of the Lower Huronian rarely outcrops in the Republic trough. Brooks on his large scale map of Republic Mountain and vicinity, 1869, shows but two exposures of the lower quartzite. They lie south of the mine, in the bend of the horseshoe, and were discovered by Pumpelly and Credner in 1867. Some 250 or 300 feet southwest of the westernmost of these, I have recently found a conglomerate resting upon granite, the contact of the two rocks being very well exposed. It is interesting to note that the locality is very close to that figured by Brooks[1] to show that the strike of the quartzite and of the magnetite-actinolite-schist just above it, runs directly across the foliation in the underlying gneissoid granite. From this he inferred an unconformability between the Huronian and the Laurentian.

II. GENERAL RELATIONS.

The accompanying map will make plain the immediate relations between granite, quartzite, and magnetite-actinolite-schist. The magnetite-actinolite-schists occupy a broad belt in the northern part of the area represented on the large scale map (Fig. V), striking between N, and E. at various angles, and dipping W. of N. from 35°–40°. The alternating layers of silica, actinolite, and magnetic, or two or all combined, which compose this rock, show both a considerable degree of plication, and also a coarse, cross cleavage which strikes between N.45°W. and N. 60° W., or roughly in the direction of the axis of the trough.

[1] Geology of Michigan, Vol. I, part I, p. 126.



N. W. ¼, N. E. ¼, Sec. 18, T. 46 N. R. 29 W., Mich.

The map is from a tracing of a manuscript copy of Brooks' Map, 1 inch = 200 feet, in the possession of the Republic Iron Co. The area represented on the large scale covers a little more than the N. W. ¼ of the N. E. ¼ of Sec. 18, T. 46 N., R. 29 W. The sketch to small scale shows the relation to the trough as a whole. (Fig. V.)

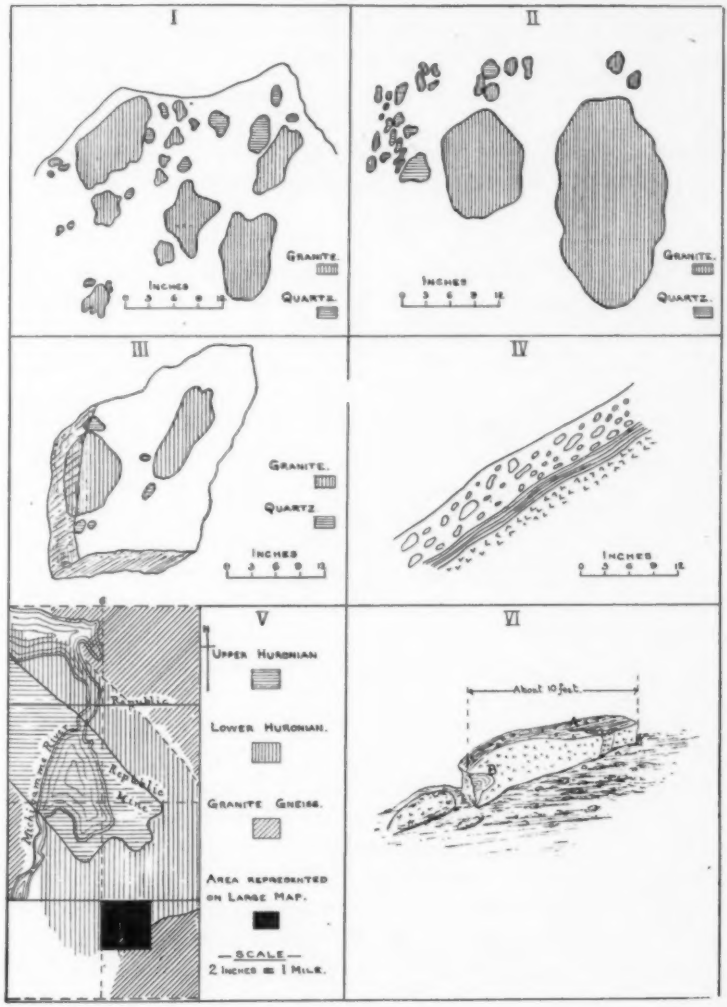
Below the magnetite-actinolite-schists and separated from the nearest exposure by a covered interval of 50 feet is the outcrop of quartzite discovered by Pumpelly and Credner. The outcrop runs about 175 feet along the strike and 30 feet across it. At the N. E. end the strike is about N. 55 °E., and at the S. W. end about N. 20° E., the dip in both cases being to the W. of N.,40°–45°. For the most part the rock is massive and heavily bedded, but the higher portion shows unmistakable sedimentary banding, and even false bedding.

In external appearance and in composition the rock is a very coarse-textured, light-colored quartzite, made up almost entirely of quartz, with some muscovite and chlorite as subordinate constituents. Under the microscope, probably because obliterated by shearing, no original rolled grains were seen, although several slides were examined. Red garnets are occasionally found in the quartzite.

A short distance south and west of the quartzite is a ridge running a little east of north, made up mainly of granite, which presents several bold faces to the west. Near the south end and on the west side, is found upon the granite a westerly dipping fringe of conglomerate, which extends some 50 feet along the strike, as a continuous rock mass. Farther north occasional small patches of conglomerate on the northwesterly sloping granite faces, indicate that the contact follows very closely the direction of the ridge, and lies near its western base.

III. Granite.

The granite exposed on this ridge occurs in both white and reddish weathering varieties, which appear to be, however, identical in composition and age. The rock is a coarse mixture of quartz and feldspar of which orthoclase is an important part, and which occurs in Carlsbad twins up to two inches in length. Light colored mica and biotite are largely developed in the planes of shearing. The granite contains much pegmatite, both in veins and in irregular masses. From the contact with the conglomerate back as far as exposures extend, the granite is


I
Granite.
Quartz.
Inches
0 3 6 9 12
II
Granite.
Quartz.
Inches
0 3 6 9 12
III
Granite.
Quartz
Inches
0 3 6 9 12
IV
Inches
0 3 6 9 12
V
Upper Huronian
Lower Huronian.
Granite Gneiss.
Area represented on Large Map.
—Scale—
2 Inches = 1 Mile.
Republic
Republic
King
VI
About 10 feet.
A
B

FIGS. I.–VI.

traversed by a rude cleavage, which has a general northwesterly direction, and so makes a large angle with the line of contact. The direction of cleavage varies between the limits of N. 40° W. and N. 60° W., and is usually represented by a multitude of planes, in which the micas only are foliated. This cleavage is more strongly developed on the western side of the exposure, near the contact, than elsewhere; and as the cleavage becomes more perfect, the large orthoclase crystals disappear.

IV. Conglomerate.

The matrix of the conglomerate varies between a somewhat micaceous quartzite and a fine grained mica-schist, and shows very distinct bands differing in color, texture, and composition. These bands are thrown into little folds, about northwesterly plunging axes; in strike they conform to the direction of the line of division between the conglomerate and the granite. In this quartzitic matrix are imbedded clearly water-rounded pebbles of quartz, granite, and of a black crystalline schist. The quartz pebbles are as a rule small, few exceeding six inches in diameter. They are of different varieties, clear, milky, brown, and blue gray quartz all being represented. All are more or less thoroughly granulated. They are of very different shapes, and within the planes of bedding, their longer axes lie in different directions. All agree in being smoothly worn and are unmistakably water-rounded.

The granite fragments vary in size from pebbles a fraction of an inch up to bowlders five feet in diameter. The larger are usually thin slabs lying with their flat sides parallel to the bedding. The foliation of the matrix often follows round the inclusions. The contacts between pebbles and matrix are exceedingly sharp; sometimes, however, where several pebbles lie close together, it is a matter of some difficulty to trace the boundary of each on the weathered surface. The distribution of pebbles is very irregular. Near the south end of the exposure they are closely packed, while the northern part of the main exposure has comparatively few. The granite of the pebbles and bowl-

ders appears to be identically the same granite as that on which the conglomerate rests. We find both the white and the red-weathering varieties represented among the pebbles of the conglomerate, and perhaps also the coarse pegmatite. Figures I and II from a sketch made to scale in the field show the appearance of the rock on the dip surface, while Fig. III, drawn to the same scale, shows the outlines of two medium-sized granite bowlders, as seen in cross section on a joint plane.

V. Contact.

At the south end of the main exposure, a nearly vertical cross joint plane on the south of which the rocks have been removed, shows the contact for eight or ten feet across the strike. The relations are represented in Fig. IV.

The conglomerate can be followed by its pebbles with great certainty. The granite below is equally unmistakable. Between the lowest pebble layer of the conglomerate and the undoubted granite, is a zone a few inches wide, that is difficult to assign with certainty to either rock. The contact otherwise is very definite and follows the dip of the conglomerate pebbles. There is no indication that the contact is not simply one of erosion. As the matrix of the conglomerate has been transformed into a crystalline schist as the result of shearing, one may easily suppose that the doubtful zone represents either recomposed granitic detritus or the broken up material of both rocks due to movement along the contact during the folding.

At the north end of the main exposure we have another natural section on a cross vertical plane, shown in Fig. VI. Here a large semi-detached mass of granite, which seems to be joined at the east end to the main mass, lies over a portion of the conglomerate. At its west end it includes a folded fragment of the conglomerate matrix four or five feet long, and two or three feet across, shown at B in the figure.

The junction between the quartz-schist and the granite is sharp, and the banding of the schist is cut at a small angle by the granite. At the east end of the granite mass, at A, a ver-

tical gash four or five inches wide, is filled with conglomerate, connecting with the conglomerate below, and tapering irregularly to a point on the upper surface of the exposure. It is clear, as Professor Van Hise has suggested, that the large mass of granite was a partly detached block of the irregular surface upon which the conglomerate was laid down, and that the sedimentary material at A and B has sifted into cracks existing in it at that time.

VI. Summary.

1. We have near Republic a conglomerate which from its relations must lie at the base of the Lower Huronian, and cannot possibly be Upper Huronian.

2. This conglomerate rests in visible contact upon granite, and is a basal conglomerate;—*i. e.*, it contains numerous water-worn fragments of the granite upon which it rests.

Henry Lloyd Smyth.

A PLEISTOCENE MANGANESE DEPOSIT NEAR GOLCONDA, NEVADA.[1]

THE LOCATION OF THE DEPOSIT.

GOLCONDA is a small settlement in northern Nevada, in the valley of the Humboldt river, on the line of the Central Pacific Railroad. A deposit of manganese ore occurs about three miles northeast of the town, on a part of the Havallah Range locally known as the Edna Mountains, and a short distance south of where the Humboldt river has cut its channel through the range. The deposit is small and of no great commercial value, but it is of interest both in the nature of the ore and in its geologic relations.

THE NATURE OF THE ORE.

The ore is a massive, black, glossy oxide of manganese with a hardness varying from 3 to 4. It is generally of a more or less porous structure, often containing cavities lined with mammillary or stalactitic forms, and it sometimes shows apparent signs of bedding. In places it is soft, earthy and pulverulent and contains angular fragments of sandstone, shale and limestone from a small fraction of an inch to several inches in diameter. Sometimes it is stained brown by iron.

The following analysis by R. N. Brackett, Chemist of the Geological Survey of Arkansas, shows the composition of a specimen of this ore dried at 110°-115° Centigrade.

Analysis of Manganese Ore from near Golconda, Nevada.

Manganese protoxide (MnO) - -	65.66
Oxygen (O) - - - -	10.31
Ferric oxide (Fe_2O_3) - - -	3.32

[1] This deposit was examined by the writer while investigating the manganese resources of the United States and Canada for the Geological Survey of Arkansas, and was first described in Vol. I. of the Geological Survey of Arkansas for 1890, J. C. Branner, State Geologist, R. A. F. Penrose, Jr., Assistant Geologist.

Alumina (Al_2O_3)	0.34
Cobalt oxide (CoO)	(not determined)[1]
Lime (CaO)	3.44
Baryta (BaO)	5.65
Magnesia (MgO)	1.26
Potash (K_2O)	0.35
Soda (Na_2O)	none.
Phosphoric acid (P_2O_5)	none.
Tungstic acid (WO_3)	2.78
Silica (SiO_2)	1.70
Water and organic matter	4.16
	98.97

Metallic manganese	50.85
Metallic iron	2.32
Metallic tungsten	2.20

It will be seen by the analysis that the ore is an impure oxide of manganese, being possibly a mixture of the peroxide and sesquioxide, though the impurities obscure its true nature. The most remarkable feature of the ore is the considerable amount of tungstic acid present, comprising 2.78 per cent of the ore and corresponding to 2.20 per cent of metallic tungsten. The form in which the tungsten exists in the ore is uncertain. It is possible that it may exist as a tungstate of manganese or iron, or of both, or perhaps of one of the other bases present. It may either have been deposited from solution with the manganese, or it may have been brought in as detritus from an outside source during the deposition of the ore, in the same way as the fragments of rock were brought into the deposit.

Though from a mineralogical standpoint the ore is impure, yet for commercial purposes the analysis shows a good grade of manganese ore, and the presence of the tungsten would give additional value to the ore in the manufacture of certain kinds of hard steel.

THE NATURE OF THE DEPOSIT.

The ore occurs as a lenticular deposit imbedded in a soft white or buff colored calcareous tufa which contains fragments of sandstone, shale and massive limestone similar to those found

[1] There is more than a trace of cobalt present but the amount was not determined.

in the ore and often in sufficient quantities to form a breccia. This material composes a small knoll on the lower slope of the mountain, and lies on the upturned edges of underlying shale. The association of the manganese and the tufa is shown in Figure 1, while the relation of the deposit as a whole to the Edna Mountains is shown in Figure 2. The first figure represents the small knoll on the left hand side of the second figure.

FIGURE 1.—*Section through the Golconda manganese deposit.*

A. Calcareous tufa. B. Manganese ore. C. Shale.

Horizontal scale: 1 inch = 125 feet. Vertical scale: 1 inch = 80 feet.

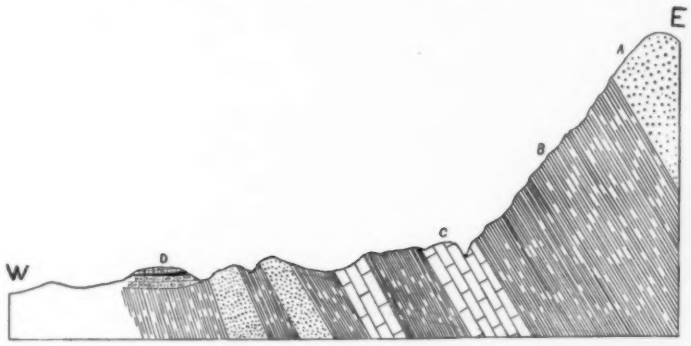


FIGURE 2.—*Section showing the relation of the Golconda manganese deposit to the rocks of the Edna Mountains.*

A. Quartzite. B. Shale. C. Limestone. D. Manganese-bearing deposit.

Horizontal scale: 1 inch = 500 feet. Vertical scale: 1 inch = 300 feet. (Both of these scales are only approximations.)

The outcrop of the ore bed appears as a horizontal black band along the side of the knoll facing the mountains, and is very variable in thickness, in some places being represented only as a black line in the white material enclosing it and in others

widening to a maximum, where exposed, of three and a half feet. On the west slope of the knoll the ore bed is not seen at all, the only trace of it being an occasional black stain or dendrites in the limestone along the line where it should outcrop if it extended through to this side. The bed also thins out to the north and south, the whole length of the outcrop being only about 400 feet. East of the outcrop of the ore, the knoll is cut sharply off, as shown in Figure 2, by a rocky area which separates it from the mountains. It will thus be seen that the amount of ore here is limited, and it is probable that the area underlain by it does not cover more than a few acres.

Beneath the ore bed, as seen in one of the small pits that have been made on the deposit, the calcareous material is soft and partakes of the nature of a marl, while above, it is often much harder and has in many places become coarsely crystalline. The crystillization seems to have taken place in spots in the bed, and frequently bodies of crystalline material are surrounded by, and blend into a massive and softer tufa of the same composition.

The fragments of sandstone, shale and gray limestone found in this deposit are of the same nature as the beds of those rocks which comprise the mountain to the east and are undoubtedly derived from them. The pieces of limestone are so markedly different from the calcareous bed enclosing them that they cannot be confounded with it. The rock fragments are of unequal distribution in the deposit, both laterally and vertically, sometimes composing almost half of it, and sometimes being almost entirely absent. They vary from a fraction of an inch to several inches in diameter and are indiscriminately mixed.

The age of the rocks composing the part of the Havallah Range lying east of the manganese deposit is represented as Star Peak Triassic on the map accompanying the Survey of the Fortieth Parallel.[1] As shown in the section given above they are

[1] U. S. Geol. Exploration of the Fortieth Parallel; Clarence King, Geologist in charge; Vol. I., Systematic Geology, map III., Pre-Mesozoic and Mesozoic Exposures. See also report of Arnold Hague, Vol. II., Descriptive Geology, page 680.

composed of sandstones, shales and limestones dipping at steep angles. The upturned edges of the rocks are well exposed from the summit of the mountain to its base, where they are covered by the small knoll or mound containing the manganese deposit.

The crest of the mountain is composed of a quartzite which is of a dark gray color, spotted with brown specks, of a granular structure, very hard and cut by numerous quartz veins. The lower beds of quartzite on the slopes resemble this one in all respects except that they show less trace of their original sandy structure and are more vitreous. The larger part of the slope of the mountain is composed of a more or less slaty shale. It is of a gray or purple color, contains large quantities of thin flakes of mica, has a wavy, undulating structure and in some places grades almost into a micaceous or talcose schist. The lower beds of shale are much thinner than this one, and in some places resemble it in general appearance, while in others they are more calcareous and blend into limestone. The shale which underlies the knoll containing the manganese (see figures) is of a light yellow color on its surface exposure, and is made up of thin friable laminæ. The limestone beds shown in Figure 2 are all of much the same character; they are of a light or dark gray color, sometimes with a reddish tinge, generally massive, though occasionally showing a tendency to a semi-crystalline structure, and are frequently cut by veins of white crystalline calcite.

THE ORIGIN OF THE DEPOSIT.

The Golconda manganese deposit is in the arid region lying between the Rocky Mountains and the Sierra Nevada, and known as the "Great Basin." Parts of this region, as is well-known, were, in Pleistocene, or Quaternary, times covered by several large inland bodies of water, of which lakes Bonneville and Lahontan, described respectively by G. K. Gilbert[1] and I. C. Russell,[2] were the largest. In subsequent times these were

[1] Lake Bonneville, Monograph U. S. Geological Survey, No. 1., 1890.

[2] Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885.

mostly dried up, and the only remains of them now are a series of much smaller lakes, occupying hollows in the bottoms of the old lake basins. Great Salt Lake is the modern representative of Lake Bonneville; and Tahoe, Winnemucca, Pyramid and other lakes occupy the basin of Lake Lahontan.

The region about the manganese deposit is on the eastern edge of the area defined by Mr. Russell as the ancient bed of Lake Lahontan, and occupies a position at the head of what was once a small bay protruding about fifteen miles up what is now the valley of the Humboldt River. Mr. Russell,[1] in speaking of the lakes which formerly existed in the Great Basin, says: "Some of these old lakes had outlets to the sea, and were the sources of considerable rivers, others discharged into sister lakes; a considerable number, however, did not rise high enough to find an outlet, but were entirely inclosed, as is the case with the Dead Sea, the Caspian, and many of the lakes of the Far West at the present time." Lake Lahontan did not overflow, and, therefore, the mineral matter brought to it in solution by tributary waters constantly increased in quantity; while the gradual evaporation of the lake steadily concentrated these mineral solutions until they arrived at a state of supersaturation, and were deposited as chemical precipitates. These were, according to Mr. Russell, largely of a calcareous nature, and were laid down as fringes on the margin of the lake at successive stages of evaporation. They are found now at different levels on the old lake border, and mark the ancient shore lines. Mr. Russell has divided them into three classes of "tufas," differing considerably in physical character, and deposited at different levels during the desiccation of the lake. He has named them in the order of their chronological succession, "lithoid," "thinolitic," and "dendritic" tufas. From the analogy of the samples of tufa collected by the writer at the manganese deposit with the description of lithoid tufa given by Mr. Russell, and from the position that the deposit occupies in the old Lake Basin, it is probable that

[1] Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885, page 6.

the calcareous material with which the Golconda manganese deposit is interbedded represents the lithoid tufa of Russell, and that the manganese itself is a local deposit not necessarily characteristic of the variety of tufa with which it is associated. In other words, the deposit represents a lenticular bed of manganese ore interstratified with a calcareous sediment, the latter having been chemically deposited from supersaturated lake waters. It will be seen in Fig. 2 that the manganese deposit occupies a basin in this tufa, that the basin was originally cut off on the east side by the rocks that formed the old shore line, and that it was bounded on its west side by the outer edge of the tufa terrace. Between these limits it extended a short distance up and down the lake shore. This position, as well as the nature of the ore, both tend to show that the bed was originally laid down as a shallow water deposit and subsequently covered over by a tufa similar to that which underlies it.

It seems possible that the origin of the ore deposit was a local accumulation of manganese precipitated from spring waters. In support of this supposition it may be stated that at the town of Golconda there are, at the present time, a series of hot springs depositing a sinter highly charged with oxide of manganese. The source of this manganese in the spring waters may have been in the igneous rocks which cover large areas in the region in question, and give strong reactions for manganese. Another possible source of supply may have been in the stratified rocks already described as forming the mass of the mountain on the slope of which the deposit is situated, as both the quartzite and the limestone contain small quantities of manganese. The igneous rocks, however, contain a larger percentage of this material than the other rocks.

As regards the mode of precipitation of the manganese, it is not probable that the ore was deposited simply by the gradual desiccation of the lake waters, as was the case with the lithoid tufa enclosing it, since, if this had been so, a far more general distribution of manganese than is seen in the tufa of the Lahontan basin would be expected. It seems more probable that the

deposit was due to a local precipitation brought on by an excess of manganese in spring waters in the locality in question, and that the cause of its accumulation was the accidental formation of a suitable basin in the tufa. This basin may either have been closed or may have had an outlet into the lake. When the spring waters reached the surface they were probably retained, at least temporarily, in the basin, long enough to allow the oxidation of the metalliferous solution and the precipitation of oxide or carbonate of manganese,[1] thus causing a local accumulation of ore; whereas, if the spring water had flowed directly into the lake, its contents of manganese would have been scattered over a vast area, and would not have accumulated anywhere in deposits of noticeable size. The rock fragments in the ore and tufa represent detritus from the mountain side carried down during the deposition of the beds.

The deposition of manganese by spring waters elsewhere than in the case in question, though in limited quantities, is not an unusual occurrence. The Hot Springs of Arkansas deposit a calcareous sinter often heavily impregnated by manganese. A hot spring near the Cape of Good Hope,[2] with a temperature of 110° Fahrenheit, deposits oxide of manganese in its discharge channel. A mineral spring in the house of the Russian Crown, at Carlsbad,[3] with a temperature of 68° Fahrenheit, also forms manganiferous deposits. The springs at Luxeuil,[4] as well as the waters in some of the mines at Freyberg,[5] also form manganiferous sediments. These deposits, however, are all very small and are simply mentioned to show the frequent occurrence of manganese deposited by springs. Cases where a black incrustation of oxide of manganese is deposited by rivers and creeks on the rocks and pebbles in their courses are of common occurrence.

R. A. F. PENROSE, JR.

[1] If the carbonate was precipitated, it was later converted by oxidation into its present oxide form.

[2] Townsend, l' Institut., 1844, No. 529. (Bischof.)

[3] Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

[4] Braconnot, Ann. de Chim. et de Phys., Vol. 18, p. 221. (Bischof.)

[5] Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

Studies for Students.

THE ELEMENTS OF THE GEOLOGICAL TIME-SCALE.

The formations, as we find them classified in this time-scale, are arbitrarily limited and classified, but back of this arbitrary classification, certain grand events in the history of the earth are indistinctly seen. The primary units of the classification are called systems. Beginning at the base of the fossil-bearing series resting upon either Archæan or rocks of uncertain age there are first, the (1) Cambrian system of Sedgwick, restricted and also expanded as the result of later investigation. Second, the Silurian system of Murchison, divided into two, the lower Silurian which, to avoid confusion, and to give definiteness to the nomenclature has been named (2) Ordovician, by Lapworth, and the upper Silurian, for which we will retain, thus restricted, the name (3) Silurian. The fourth system, (4) Devonian, was proposed by Murchison and Sedgwick. The (5) Carboniferous system follows, which was early defined in Geology, but it is not clear who first proposed the name early applied to the coal-bearing rocks. Above this is the (6) Triassic system of Bronn, followed by the (7) Jurassic system of Brongniart. To the next system the name (8) Cretaceous was applied by Fitton. The next system still retains the name (9) Tertiary, of Cuvier and Brongniart, and is terminated by the (10) Quaternary system, whose name was introduced by Morlot. Tertiary and Quaternary were applied on the plan of Lehmann's classification which, in other respects in the course of events, has dropped out of the nomenclature.

Without explaining how the series of stratified rocks come to be divided into these particular ten systems, it may be said that their retention is due mainly to the relatively sharp boundaries

which each system exhibits in its typical locality. The systems thus serve as known and definite standards of comparison in the construction of the time-scale, as the dominance of nations or the dominance of the dynasties in each serve as time standards for the discussion of ancient human history. As the period of each dynasty in ancient history is marked by continuity in the successive steps of progress of the country, of the acts of the people and of the forms of government, and the change of dynasties is marked by a breaking of this continuity, by revolutions and readjustment of affairs, so in geological history the grand systems represent periods of continuity of deposition for the regions in which they were formed, separated from one another by grand *revolutions* interrupting the regularity of deposition, disturbing by folding, faulting and sometimes metamorphosing the older strata upon which the following strata rest unconformably and form the beginnings of a new system.

Geological revolutions were not universal for the whole earth; from which it results that these typical systems and their classification are not equally applicable to the formations of all lands. It is important also to note that the geological revolution was not a sudden catastrophe but the culmination of slowly progressing disturbances bringing the surface of the region concerned ultimately above the level of the ocean, the ocean level being a pivotal point in geological rock formation. The area whose surface is below the sea level may be accumulating deposits and making rocks, but so soon as the same region is lifted above the surface it becomes a region of erosion, destruction and degradation. Whenever, therefore, in the oscillations of level any particular part of a continental mass of the earth's crust passes permanently, or for a long geological period of time, above the sea level, a great event in geological history has culminated. In case the elevation is only temporary the event is marked by unconformity, or a break in the continuity of the formations; when it is permanent the geological record for that region ceases except so far as fresh water deposits in lakes may continue independent records. Hence it is that these periods of revolution are of such import-

ance in the history of the continents, and constitute the most satisfactory marks for the primary classification of geological history.

The natural geological system is a continuous series of conformable strata. A geological revolution is expressed by unconformity and more or less disturbance and displacement of the strata from their original position. The grander revolutions are also recorded in the permanent elevation of mountain masses or extensive continental areas, above the level of the sea and thus out of the reach of later strata accumulation. The most widely recognized revolution in geological time, since the close of the Archæan, separates the Carboniferous from the Triassic system. In American classification, following Dana's usage, it may be called the Appalachian revolution. It terminated the series of formations which, with only minor interruptions, had been continuously accumulating in the Appalachian basin from the early Cambrian period onward. It left above the sea level not only all the Appalachian region but the great part of the eastern half of the continent, extending westward beyond the Mississippi river to a line running irregularly from western Minnesota to Texas. This revolution produced the Allegheny mountains, and those flexings and faultings which are still recognized in the line of lesser ridges extending from Pennsylvania to Georgia. In England, Northern Europe and Northern Asia like disturbances took place at the same general period of time. In Australia, Southern Africa and South America, the indications are that the revolution was not so extensive, if it took place at all at the same time. The probabilities are that while it was almost universal for the northern hemisphere it was mainly confined to this half of the earth. The Appalachian revolution was not limited to a brief geological period but beginning near the close of the coal measures of the east it did not become effective in the region of Kansas and Nebraska till the close of the Permian. The wide extent of the disturbance of strata and consequently of records at this point in the time-scale has led to making here a primary dividing point of the scale, marking off Palæozoic time.

Several lesser, more or less local, revolutions have left their permanent mark in the grander structure of the rocks or in conspicuous geographical features of the restricted region of the continental area. The first of these was the Green mountain revolution which separated the (Lower Silurian) Ordovician from the (Upper Silurian) Silurian, for the eastern part of North America. The elevation, disturbance and metamorphism of the rocks of the Green Mountains stand forth as monuments of this event. The revolution is not sharply distinguishable in the rocks of the more southern or western regions. The second of these lesser revolutions is expressed most sharply in elevation and unconformity terminating the Devonian formations of Maine, New Brunswick and Nova Scotia, and may therefore be called the Acadian revolution. In the continental interior it may be indicated by the remarkable thinning out of the Devonian rocks toward the southwestward. In Tennessee, Alabama and Arkansas they are represented by a thin sheet of black shale, a few feet thick, or by but little more than a line of separation between the rocks of the Silurian below and the Carboniferous beds resting scarcely unconformably upon them. This seems to indicate an elevation of the region still further south toward the close of the Devonian, sufficient to produce extensive erosion, uncovering the Lower Silurian rocks which were again depressed to receive the marine deposits of the early Carboniferous upon their eroded surfaces.

The Appalachian revolution closed the Palæozoic time and left the great part of the eastern half of the continent above sea-level. It forms the natural interval between the Carboniferous and the overlying system, whatever that may be. Its characterteristics have already been described.

The Palisade revolution, along the eastern border of the continent, marks the division between the Jura-Triassic part of the Mesozoic time and its closing Cretaceous age. It is expressed by the trap ridges in the Connecticut valley, the Palisades and other similar tracts distributed inside the coast from Nova Scotia to North Carolina, and by the uptilting and in some cases fault-

ing of the underlying red sandstone and shale, and the resulting unconformity with the succeeding formations. The evidences of the revolution are not widely extended nor is the time relation of the termination of the revolution sharply defined, but it is sufficiently so to form a natural boundary line separating the Jura-Trias from the Cretaceous. After this point of time there occurred nothing in the eastern half of the continent which deserves the name or rank of a geological revolution. The western part of the continent is conspicuous for its grand geological construction after the Triassic at least; along the coast the Sierra Nevada revolution marked the same general interval of time recorded by the Palisade revolution of the east. These events on the opposite borders of the continent are alike at least in preceding the Cretaceous and in terminating the formations which are of Jura-Triassic age.

The Rocky Mountain revolution, which resulted in the elevation and disturbance of the rocks in the region of the Rocky Mountains, and extended from them to the border ranges, is distributed along the time from the close of the Cretaceous to the Miocene, or possibly later. It is altogether probable that the actual length of time, taken in the elevation, tilting and disturbance of strata after the last marine deposits of the pre-Laramie formations, which resulted in the permanent adding to the continent of its western third, was not longer than that consumed in the various events terminating the Palæozoic, and making into permanent land the great mass of the eastern half of the continent. This Rocky Mountain revolution resembles the Appalachian revolution, in extending over and affecting a large area of the continent, in its general upward-lifting of that area, which process extended over a long period of time, and in the great accumulation of coal or lignite which was associated with the gradual emergence of the continental mass above the sea-level.

Another feature in which the two revolutions resemble each other is found in the wide extent of the disturbances recorded. The elevation of the mountain ranges from the Pyrenees east-

ward to the Himalayas, and to the islands beyond, took place chronologically at the same general period, and that this series of disturbances may have affected the whole of the northern hemisphere is further suggested by the occurrence of gigantic erratic blocks of granite in the midst of Eocene strata in the neighborhood of Vienna and other places. Vezien (Rev. Sci. XI., p. 171, 1877) has suggested that an ice-age is indicated by these events.

This Rocky Mountain revolution marks the period of the second great break in the life of the geological ages. The Mesozoic time began with the close of the Appalachian revolution, and closed with the elevation of the Cretaceous beds above ocean-level. In our classification the division line between the Cretaceous and Tertiary was arbitrarily placed at the top of the chalk formations conspicuously developed on both sides of the British Channel. The difficulty American geologists have had in drawing the precise line to separate the Mesozoic from the Cenozoic has resulted from the change of the character of life in the beds in the western interior from marine to brackish, fresh-water and land types. This change was incident to the Rocky Mountain revolution, which had already begun, and was slowly lifting the whole region while the Laramie sediments were being laid down. Several stages may be marked in this grand revolution, but the facts connected with them are not so well-developed as to serve for general purposes of classification of the time scale.

At the close of the Miocene, a great outflow of lava in the northwestern part of the United States took place, and continued with interruptions through the Tertiary into the Quaternary time. About the Columbia River, where it cuts through the Cascade range, the basalt is over three thousand feet thick, and the outflows cover a vast extent of territory, estimated at 150,000 square miles. This was incident to the vast earth disturbance which raised to the amount of at least five thousand feet a large part of the western half of the continent.

There was, still later, a revolution which has left little record in the way of disturbance or discordance of strata, but was of

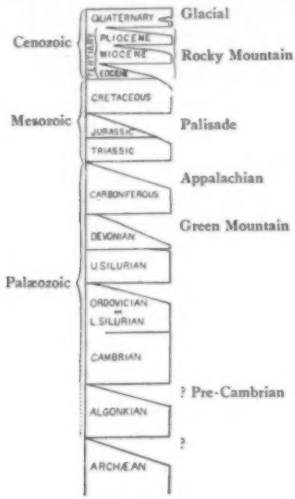
particular importance in life-history, as it introduced the recent period, or the age of man. This is the combination of events marking the glacial epoch. In general, it consisted geologically of oscillations of the northern lands for the northern hemisphere, and was associated with the accumulation of ice upon the surface and its continuance as a great ice-sheet for a long period of time. Some of the more accurate estimates of the length of geological time are based upon the rate of erosion or gorge-cutting by rivers, and the period so measured dates back to the last uncovering of the river channels coincident with the northward withdrawal of the ice-sheet. Standard examples are the estimates of the time required to cut the Niagara River gorge, and the retreat of the falls of St. Anthony from Fort Snelling to their present position, as beautifully elaborated in Winchell's Report on the Geology of Minnesota, vol. 2.

The above revolutions are selected, not as the only revolutions interrupting the regular course of sedimentary formation of stratified rocks, but as chief examples of such interruptions in the North American scale. All along the course of geological time there are evidences to show that there were constant oscillations of the relations between land and ocean-level, and at some localities these oscillations were passing across the datum plane of the ocean surface. Wherever this happened, on one side rocks were forming, and on the other erosion and degradation obliterating them as time-records. The Appalachian and the Rocky Mountain revolutions constitute the two grander revolutions. The first closed the Palæozoic life Period, the fossils being chiefly marine until the Devonian, and being associated with marine forms up to the close of the Carboniferous. The deposits are distributed across the continent, with local interruptions. After the Appalachian revolution the eastern half of the continent, except its Atlantic and Gulf borders, became permanently above the sea-level.

The period between the Appalachian and Rocky Mountain revolutions is the period of the Mesozoic life. In the faunas and floras of this period, land and fresh-water species take a promi-

nent part. The marine life is distributed over the western half of the continent and along a narrow line of formations on the Atlantic and Gulf borders. After the beginning of the Rocky Mountain revolution, the deposits of marine origin and their faunas were distributed on the marine borders of the continent as it now is, and fresh-water and land deposits were accumulated over the plains and plateaus of the western half (with few exceptions) of the continent.

Thus the grander revolutions recorded in the development of the American continent break up the geological time-scale expressed in the systems of stratified rocks into a few natural subdivisions, as may be illustrated by the following diagram:



In the use of the time-scale for the study of the history of organisms, the places marked by the revolution are those in which are found the grander interruptions to the continuity of the record. They may represent periods of great relative magnitude. They do represent periods of marked change in the faunas and floras over extensive regions. Between the grander intervals of revolution the records of life-history are relatively

continuous. There were series of successive faunas or even subfaunas, in which were expressed the general features of the evolution of life on the globe. The species preserved and known present but a very imperfect representation of the species that were living; but of those preserved in one formation there are generally found in the succeeding formations representatives of the same or closely allied genera; so that for the kinds of organisms whose remains are best preserved the record is fairly continuous for the grander rock-systems in terms of the generic, and in some cases of the specific characters.

While the conditions of deposition for a particular region remained relatively constant and uniform, the strata were accumulated in successive beds one upon another, and then the thickness of the deposits of the same kind, with proportionate thickness for deposits of different kinds, constitute a scale of definite time value; a foot of deposit representing a period of time, and the relative time-separation for two faunas would be represented by the thickness of the strata between them. It was on this principle that the time-ratios of Dana were estimated. The maximum thickness of the known strata of each geological system was taken. The limestones were assumed to represent five times the time-value that is represented by the other sedimentary deposits per foot; or in other words, every foot of limestone was estimated as equivalent to five feet of other sedimentary deposits in making up the time-ratios. On this principle Dana estimated the time-ratio for the several geological periods to be as follows:

Quaternary	¼	Cenozoic 1.
Tertiary	¾	
Cretaceous	1	Mesozoic 3 +.
Jurassic	1¼	
Triassic	1	
Carboniferous	2	Palæozoic 12 +.
Devonian	2	
Silurian (Upper)	1¼	
Ordovician (Lower Silurian)	6	
Potsdam	1	

Ward, in the fifth annual report of the United States Geological survey, has proposed to adjust these proportions as follows:

Quaternary-Recent	1
Miocene-Pliocene	1
Eocene	1
Cretaceous	1
Jura-Trias	1
Permo-Carboniferous	1
Devonian	1
Silurian	1
Cambrian	1

thus forming nine divisions of equal length.

Since Dana's estimate additions have been made to the known thickness of the Cambrian rocks of North America, which should lengthen the Cambrian ratio to 5 in the above table, and duplications of thickness due to confusion in regard to the Quebec group may reduce the Ordovician (Lower Silurian) to 5, and the Cretaceous ratio may be somewhat enlarged. The Tertiary estimate in Dana's ratios assumes the thickness to be of less ($\frac{1}{2}$) time-value because of the increased rate of deposition due to transportation of rivers. This and many other factors enter in to complicate the time-value of thickness of strata; but it must be granted that the thickness of the sediments is the prime factor in determining these time-values of the geological scale. However, the conditions of deposition, the fineness or coarseness of the clastic fragments, the abundance or rarity of supply of materials and other variable conditions must be taken into consideration in an accurate reduction of thickness of strata into length of time. Errors, also, whose value is almost impossible of estimation, arise from the intervals between strata, particularly those where unconformity exists.

After all these uncertainties are weighed the time-ratios formed on this general basis are of great importance in studying the history of organisms, and the value of accuracy in the time-scale is a sufficient reason for calling attention to the points in which greater

accuracy may be attained by further investigation. It is doubtful if it is possible with our present knowledge to reach an estimate in years or centuries, of the actual length of geological time, which is within 100 or perhaps 200 per cent. of the truth. We may accept Dana's estimate of at least 48,000,000 of years, or Giekie's of from 100,000,000 to 680,000,000. We find at one extreme the ancient theory of 6,000 years and at the other McGee's possible maximum of 7,000,000,000 years.

The rate of accumulation of sediment over the bottom of the sea may vary between the limits of one foot in 730 years and one foot in 6,800 years, as pointed out by Geikie, the figures being based upon the estimated proportion between the annual discharge of sediment in cubic feet and the area of river basins in square miles, in the case of the rivers Po and Danube. The estimate of 680,000,000 of years, quoted above, is dependent upon the assumption that the total thickness (maximum) for the sedimentary deposits is not less than 100,000 feet, and that the average rate of accumulation was not more rapid than that now going on at the mouth of the Danube, based upon Bischof's determination of the amount of sediment and matter in solution in the Danube at Vienna. It may be a query worth considering whether the estimates based upon the examination of the amount of suspended and dissolved matter in river water are not likely to err in the direction of too small amount of matter by reason of the abnormal precipitation along the course of the river incident to the presence of salts and acids put into the river by man. If the rate of the river Po were taken the length of time would be 73,000,000 of years instead of 680,000,000.

The actual length of time in years, however, is of less importance to the geologist than the relative length of time for each of the ages, and these latter, the time-ratios of Dana, are clearly deducible from the physical thickness and size of constituent particles of sedimentary rocks. Relative thickness is certainly one of the elements in the determination of the time values of the geological formation, and the fields for investigation along which greater accuracy is to be reached cover the problems of

the rate of accumulation of muds, sands and pebble beds, and of the formation of limestones, in relation to each other and under varying conditions, and the detection of the marks in the strata recording the conditions incident to the varying rates of accumulation. Until the evidence is fuller the time-ratios of Dana may be adopted as expressing approximate values for the various geological ages.

In all these studies in which the geological time-scale is applied to the evolution of the earth and its inhabitants, the time concerned is not human chronology but is what may be called *geochronology*. For this purpose we need a standard time-unit or *geochrone*. The geochrone applied in Dana's time-ratios appears to be 8,000 feet of sedimentary deposits, as in the Potsdam, (7000 feet sediments and 200 limestone). Something more definite is needed and one in which the equivalents in different kinds of deposit and in different regions can be studied and compared with some approach to accuracy. The Eocene period, as expressed in the gulf states on both sides of the Mississippi river, might be selected as a convenient and practicable standard for this purpose. Humphrey and Abbot's elaborate studies of the Mississippi river furnish minute data for comparison with recent conditions. There are 3,000 feet of marine beds referred to the Eocene in southern Europe. The Eocene or early Tertiary fresh-water beds reach a thickness of at least 10,000 feet. The Tertiary beds in Liguria are estimated to reach the thickness of 23,600 feet. If for the present we assume the Eocene geochrone to be equivalent to the maximum deposit of 3,000 feet of fragmental sediment on the edge of the continent, using Dana's estimates of time-ratios with some modifications, and adopting the term Eocene as the American students of marine Eocene apply it, the following standard time-scale for geochronology is constructed. The geochrone in this scale is the period represented by the Eocene, as understood in North America to include the marine deposits and their faunas, from the close of the Cretaceous to the top of the Vicksburg or white limestone of Smith and Johnston, 1,700 feet of which are seen in Alabama. In England it

may include the Oligocene to the top of the Hempstead beds. I realize that such a proposition furnishes many points for dispute. The scale is open for correction, and the standard may be defined with greater precision. But it is offered as a working hypothesis, to aid and stimulate investigation.

Such a standard time-scale of geochronology, on the basis of the Eocene period for a time-unit or geochrone would read as follows:

Recent, Quaternary	1	
Pliocene, Miocene	1	= 3.
Eocene	1	
Cretaceous	4	
Jurassic	3	= 9.
Triassic	2	
Carboniferous	6	
Devonian	5	
Up. Silurian	4	= 45.
Low. Silurian or Ordovician	15	
Cambrian	15	

The proximity of the Eocene of the Gulf border to continental conditions now in operation, the abundance of its marine fauna for comparison with like faunas of earlier or later age and of the same or different habitats, and its inclusion of traces of land-life for correlation with other conditions, and, in general, the wide distribution of available Eocene deposits and faunas for comparative study, are reasons for calling attention of investigators to this particular field for minute investigation in perfecting the geological time-scale.

HENRY S. WILLIAMS.

EDITORIALS.

THE United States Geological Survey is to be congratulated upon the appearance of the first atlas sheets of the geological map of the United States which, although still considered as preliminary to the regular edition, may be taken as essentially finished, and as embodying the chief features which will characterize the completed work. Each atlas consists of one portion of the whole map printed in four ways: one presenting the topography by itself; one, the areal geology; another, the geological structure by means of cross sections, and a fourth, the features of economic importance. Accompanying these are sheets of text, one of which explains certain elementary concepts of the science and defines the sense in which some of the more common terms are to be employed throughout this series of publications. The text describing the special area surveyed is admirably prepared to set forth in a concise manner the leading features of the geology and of the economic resources. It is prefaced in some cases by a general sketch of the region immediately surrounding the area published, which aids materially the comprehension of the more local geology. In one instance, however, the sketch embraces nearly the whole eastern portion of the United States, which seems unnecessary since, we assume, it is not the intention of the Survey to do away with the publication of its monographs and bulletins, where the full results of the several investigations should appear. Otherwise, the text accompanying the atlas sheets would be insufficient.

The sheets finished are from widely separated parts of the country: the Hawley sheet in Massachusetts, the geology of which is by Professor B. K. Emerson; the Kingston sheet in Tennessee, the geology by Mr. C. Willard Hayes, assisted by

Mr. M. R. Campbell; the Lassen Peak sheet and Sacramento sheet in California, the geology of the former by Mr. J. S. Diller, that of the latter by Mr. W. Lindgren. The character of the geology is equally diverse, embracing highly metamorphosed sediments in the first case, slightly modified strata in the second, and in the last two, metamorphosed igneous and sedimentary rocks associated with volcanic lavas. We notice with satisfaction the prominence given to economic features as well as the clear statement of facts regarding the dates at which the work was prosecuted, and the investigators who are to be credited with the work, two essential elements in forming a judgment as to the character of the results.

While the atlas sheets are alike in size they differ in scale from 1-250,000 to 1-62,500. The relative areas, however, are shown upon an index map on the cover of the atlas. These differences of scale are desirable because of the variable importance of the different parts of the country, and the variability in the character of the geology, which may be best represented upon maps of different scales. Such flexibility is a distinct advantage. The success of the effort to introduce greater elasticity into the method of coloring geological formations will be variously estimated. It is not possible to form a fair opinion of the merits of the system from the few examples of it furnished by the four atlas sheets already finished. But it would seem that the prominence accorded to pattern in the system, by making it a basis for the distinction of the main subdivisions of rocks: sedimentary, igneous and metamorphic, has been nullified by the lithographer, who has succeeded so admirably in reducing the lining to a mechanical minimum that the detection and recognition of patterns is a test of eyesight. We appreciate the difficulties attending the application of any comprehensive scheme of colors to so large and diversified a series of atlas sheets as that which will constitute the map of the United States, and look upon the efforts so far made as having advanced the problem without completely solving it. In the meantime the results already obtained by the geologists of the Survey in many

parts of the country should be published without waiting longer for a perfect method of coloring to be devised. J. P. I.

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Do oscillations of the crust progress by waves? Or are they limited to non-progressive vertical elevations and depressions, or to oblique thrusts and resiliences? Or are there both stationary and progressive oscillations?

The subject does not seem to have received much definite investigation, although it finds incidental expression here and there in geological literature. It is clear, however, that a determination of the stationary or progressive character of crust oscillations must have an important bearing upon the various hypotheses that concern the relations of the earth's crust to its interior. It is obvious that preliminary to a study of these problems there must be dismissed from consideration those merely apparent oscillations of the crust that are in reality but variations of the sea level. It seems quite certain, however, that when these are eliminated there remain a large class of true crustal movements. The elucidation of these is extremely difficult and would be greatly aided if it were known whether they are local or migratory, and, if migratory, whether there are any general laws governing the direction of their movements, their rate of progress, etc. If migratory, do these undulations radiate from a point of origin in all directions, like the wave circles induced upon a liquid surface, or do they, like tidal waves, creep forward in a single direction?

If we combine by free hypothesis the elevations and depressions of the Pacific coast during the Pliocene and Pleistocene times with those of the Mississippi basin and of the Atlantic coast, it is not difficult to construct a procession of elevations and depressions creeping successively across the continent. Is such a synthesis supported by any close definite data indicating progressive undulation, or is it merely an artificial combination of selected data thrown into order arbitrarily at the suggestion of an hypothesis? This illustrates a class of questions whose solution presumably leads back to crustal and sub-crustal agencies.

Another class presumably involve superficial loading and unloading, as, for example, the accumulation and dissipation of continental glaciers. These are less radical in nature and less general in applicability, but perhaps offer greater hopes of early solution. There are few problems in geology more difficult of satisfactory elucidation, even by hypothesis, than the moderate but widespread oscillations of the earth's crust. The problem of mountain building, though more obtrusive, seems really less difficult than that of plateau formation, and that of plateau formation, in turn, less unpromising than that of the common widespread crustal oscillations.

The writer has become interested in these questions in connection with some studies of the earth's crust and interior, and would welcome contributions to the subject either for publication or for personal information. T. C. C.

Reviews.

Monographs of the U. S. Geological Survey, vol. XVII. The Flora of the Dakota Group. A posthumous work by Leo Lesquereux. Edited by F. H. Knowlton. 256 pp., 66 plates. Washington, 1892.

The posthumous issue of this product of many years of labor, including some of the best work of one who for many years was distinguished as the highest authority in American paleobotany, is a matter of great interest to both paleontologists and biologists, since it renders the plant remains of the Dakota group, one of the oldest dicotyledon-bearing terranes, the most completely-elaborated and best-known flora, perhaps without exception, of any restricted formation in the world. Within its two hundred and fifty-six quarto pages, four hundred and sixty species are described, or, in the case of those concerning which no new observations had been made since the publication of his "*Cretaceous Flora*" and "*Cretaceous and Tertiary Floras*," enumerated with references to his earlier works. The drawings, a considerable number of which were unfinished at the time of the author's death, occupy sixty-six plates.

Of the flora, as a whole, over ninety per cent. are dicotyledons, one and three-tenths per cent. ferns, three and one-half per cent. conifers, and two and one-half per cent. cycads. In this overwhelmingly dicotyledonous flora, most of our American living tree-families have their representatives. While going over the descriptions and figures it will seem to some readers that the number of species, and particularly of varieties, is, in some instances, too great, there being for example, four varieties of *Salix proteæfolia*, seven of *Viburnum Lesquereuxii*, and fifteen of *Betulites Westii*, especially since we are left to infer in the latter case that all have the same rather indefinite habitat, "Ellsworth County, Kansas." But, while it is probably true that some of the variations do not vary more than the leaves on a single tree, still it should be borne in mind that that period in the history of the dicotyledons, soon after their first appearance in the Cretaceous, was one of immense diversity of form and great modification of character; and, although, as Professor

Lesquereux himself suggested, their differentiation might, under other circumstances, be "hazardous," yet the discrimination of the forms furnishes a better paleontological basis for the interpretation of modern types, as well as a higher degree of definition, for the use of paleontological stratigraphy.

At the close of the memoir, the broad range of the author's knowledge and paleobotanical experience is well shown in some thirty pages, devoted to an "Analysis" of the flora of the group. From this analysis, which is of great value to the biological paleontologist, he reaches the conclusions that, although but one-fourteenth of the species found in the Dakota group are also found in the Atane beds of Greenland, yet, considering the remoteness of the regions, the close relationship of the floras, and the difference in latitude, and, perhaps, in soil, the proofs are "really conclusive" of the synchronism of the two formations; "that most of the types of the arborescent flora of North America were present in that of the Dakota group, and that most of them had left remains of allied specific or generic forms in the intermediate periods," so that the flora of this continent is indigenous; and that "all the plants of the American Cenomanian, except those of Ficus and Cycads," which, he explains, may be omitted, "might find a congenial climate in the United States between 30° and 40° of latitude," a continued uniformity of climate, causing "the preservation of the original types of the flora, subjected to some modification of their original characters, without destroying them or forcing their removal by the introduction of strange or exotic forms."

Although a great proportion of the species found in any given locality are not reported from any other point, it will readily be understood why no attempt is made to work out any floral horizons in the Dakota group, when the reader observes that, while a portion of the species are reported from among a dozen localities, and a few specimens come from Minnesota and Nebraska, owing to the circumstances attending their collection and accumulation in Professor Lesquereux's hands, a large part, perhaps the greater number of them, have no more restricted habitat than "Ellsworth County, Kansas," or merely "Kansas." It is noted, however, that in one or two instances no change in the associations of the species was met in descending fifty or seventy-five feet in the series. The geological interest of the work would have been further increased if collections from the southwestern extension of the group had also been made and studied with the rest.

In the interpretation and elaboration of the author's last notes, some of which were fragmentary, and written after the lamented writer was unfit for work, as well as in interpreting and rearranging the extensive additions or modifications to the manuscript, Professor Knowlton, the editor, has shown great discretion, making no alterations or enlargements other than those necessary to the expression of the author's intended meaning, or for priority or consistency, such alterations being indicated by brief foot-notes. To him we are also indebted for a valuable tabulation of the geological and geographical distribution of the species, a compilation involving much time and consultation of the literature of the science.

It is unfortunate that those plates with washed drawings, made under Professor Lesquereux's personal supervision for the lithographer, should have, for financial reasons, been sacrificed, even though the photo-gravure work is of good quality. Much distinctness of the nervation is lost, as may be noted in a comparison with the last plates in the volume, prepared especially for the cheaper process. Although, as in too many of the paleontological publications of the United States Geological Survey, the date on the title page is earlier than the actual publication of the work, the date (1892) on the outside page is, in this instance, correct. DAVID WHITE.

Cretaceous Fossil Plants from Minnesota. By LEO LESQUEREUX. Vol. III., Final Report on Geology and Natural History Survey of Minnesota. Feb. 15, 1893, pp. 1–22; pl. A. B.

The distinguished author of this short paper died in 1889, yet the evidences of his untiring energy are still coming to hand. This paper, bears internal evidence of having been prepared about the time of the completion of his *Flora of the Dakota Group*, which has likewise only just been published. It is prefaced by a short interesting account of the introduction and development of plant-life, illustrated by a wealth of examples and statistics.

Cretaceous fossil plants have been known from Minnesota for many years, in fact, several species were obtained by members of the Hayden survey, but this is the first complete systematic review of them. They come mostly from New Ulm, in Redwing Co., and Goodhue township in Goodhue Co. The amount of material examined was very scanty, there having been but fifty-five specimens, yet the richness of the flora is shown by the fact that there are twenty-eight species. Of this num-

ber, no less than eight are described as new to science. The new species belong to the genera Sequoia, Populus, Cissus, Alnites, Ficus, Diospyros, and Protophyllum. To these must be added four forms not specifically named, leaving sixteen species, having a distribution outside of the State of Minnesota. Of these sixteen species, fourteen are found in the Dakota group of Kansas and Nebraska, and six in the Cretaceous of Greenland, four species being common to the two localities. The species described as new, are more or less closely related to the forms from the Dakota group, or from the middle Cretaceous of Greenland, the whole serving to fix very definitely the horizon from which they came. The new, or especially interesting species are clearly depicted on the plates.

There are several obvious typographical errors as 'Kovne' for 'Kome,' 'nibrasciensis' for 'nebrascensis,' etc., which doubtless would not have occurred, had the author lived to read the proof himself.

F. H. KNOWLTON.

On the Organization of the Fossil Plants of the Coal-measures. By W. C. WILLIAMSON. Philosophical Transactions Royal Society, London: vol. 184 (1893) B. pp. 1–38; pl. 1–9.

This memoir, the nineteenth of this invaluable series, is devoted mainly to a consideration of the structure of *Lepidodendron Harcourtii.* This now classic plant was first named and described by Witham in 1833. It was also figured and described anew by Lindley and Hutton in their *Fossil Flora of Great Britain,* and was still later made the basis of an elaborate memoir by Adolph Brongniart. It was then referred by Brongniart to the cryptogams, but when he later discovered in allied forms, a secondary woody zone, developed exogenously outside of the central woody cylinder, he concluded that it must be a conifer. Williamson has long ago shown that the Lepidodendra frequently develop this secondary woody zone in mature stems, and that they are undoubted cryptogams. He was, however, unable to prove this for *L. Harcourtii,* for specimens well enough preserved to show internal structure, had not been before discovered. The present paper deals in an elaborate manner with all the authentic specimens, including the type of this species, and the author concludes that although none of the specimens were large enough to show the secondary thickening, this species is a true Lycopod, not unlike others of the genus Lepidodendron. Incidentally, the so-called genera Halonia and Ulodendron are treated of, the conclusion being that they are simply different forms of fruiting branches of Lepidodendroid and Sigillarian plants. This paper has a pronounced geological value, in that it affords a readily recognizable fossil, characteristic of a definite horizon.

F. H. KNOWLTON.

Analytical Abstracts of Current Literature.

Summary of Current Pre-Cambrian North American Literature.

Prefatory Note.—The summary of current pre-Cambrian literature beginning in this number, which will continue in following numbers, though probably not consecutively, is made upon somewhat different principles from those ordinarily used. The fundamental ideas of the plan are as follows: The summary proper and the comments are kept wholly separate, in this way preventing the confusion which frequently comes from a mingling of the two. In the summaries the original language of the author is used as far as practicable, although a single sentence may be taken from several sentences of the original. Where it is disadvantageous to use the original language other words are used. This often is necessary, because the language which is adapted to complete exposition is often not the best adapted to résumé. No quotations are made; for the ideas contained, whether in the original language or not, are wholly the ideas of the author, the whole is in fact really quoted. It might be thought that better results would be reached by indicating through quotations what words are taken from the original, but this method would necessitate an unpleasant and constant alternation from quoted to non-quoted phrases. As a result of experience with the two methods, the editor feels certain that he is able more accurately and fully, in a brief space, to represent the ideas of the original author by the method proposed, than by following the usual method.

The summaries are confined to articles or parts of articles pertaining to pre-Cambrian stratigraphy. Purely economic or petrological articles are not summarized unless they concern pre-Cambrian stratigraphy, in which case the substance of the conclusions are given, rather than a full account of the observations and the manner of reaching them. The abstracts have the defects of all summaries,—a certain amount of inaccuracy, because many modifying and qualifying facts can not be given, and because undue emphasis is placed upon the conclusions.

In many cases no comments are made. This does not imply that the editor agrees with the statements of the summaries. To criticize, qualify, or refute the statements of the authors in all cases of disagreement, would often

result in extending the space taken by the comments beyond that required for the summaries. However, when the points at issue are of general interest, or fundamental importance, it is advisable to make comments and enter into discussions, even if the space taken by such comments be greater than that given to the summary of the original articles. In such comments neither commendation nor censure will be made, but the aim will be to point out the conclusions announced which fail of complete establishment, and the generalizations which appear to go beyond what is warranted by the facts published. The purpose of indicating what appears to the editor as deficiencies of these kinds is neither to put himself dogmatically in opposition to the statements of the author reviewed, nor with the belief that his opinion has more weight, but to direct attention to the questions involved, and in cases of doubt to keep them open for farther study in the field and laboratory.

Mills[1] finds in the Sierra Nevada, unconformably below the Mesozoic, eruptive granites and sedimentary slates and quartzites. The latter in places rest and were probably deposited upon the granite, while in other places they are contemporaneous and imbedded within it. The quartzites are held to be silicified phases of the slates. These rocks in age may run from Archæan to the Paleozoic and some of them may be early Mesozoic.

Darton[2] finds Ordovician fossils in the crystalline slates and schists of the Piedmont plain of Virginia, these rocks having been previously regarded as Huronian.

Lesley[3] gives a summary sketch of the pre-Cambrian rocks of Pennsylvania, the facts being taken from the detailed state reports. The Highland Belt of New Jersey and Pennsylvania; the Reading and Durham Hills; areas in Chester, Bucks, Montgomery and Delaware counties; and an area on the Schuylkill river are placed in the Archean. All are regarded as sedimentary in origin, because of the presence of marble, apatite and iron ore. The newer gneiss of the Philadelphia belt, the Azoic formations of York, Chester and Lancaster counties, and the South Mountain rocks are not definitely referred to any system. The term Huronian must be used simply as a proper and private name for a series of rocks exposed along a part of the northern boundary of the United States. Should a similar series appear in some other region and be called Huronian on account of the resemblance, the name would have no value whatever; unless we should imagine that in a so-called Huronian age the whole surface of the planet was stuccoed with a certain formation; and

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[1] *Stratigraphy and Succession of the Rocks of the Sierra Nevada of California.* James E. Mills. Bull. Geol. Soc. of America, vol. 3, 1892, pp. 413–444.

[2] *Fossils in the "Archæan" rocks of Central Piedmont Virginia.* N. H. Darton. Am. Jour. Sci., 3rd series, vol. 44, 1892, pp. 50–52.

[3] *The Laurentian and Huronian Formations*, by J. P. Lesley, in A Summary Description of the Geology of Pennsylvania, Vol. 1. Rep. Penn. Geol. Sur., 1892, pp. 53–164.

received successive coats of other kinds of rock in after ages. The most dissimilar series of formations are known to be of the same age. What is happening to-day has happened in all ages. Nothing could be more unlike than the deposits now forming along the various ocean shores, and in different lakes and inland seas; yet they are all of one age. Even the deposits making in one and the same basin radically differ; as, for example, along the northern and southern sides of Lake Ontario; and along the eastern and western sides of Lake Champlain. It would therefore seem a useless task to seek for the Huronian rocks far from their native range.

Nason[1] fully describes the iron ores of the porphyry region of Missouri, and incidentally treats of the associated rocks. The porphyries usually show evidence of bedding, but this may be that of igneous flows. The Cambrian limestones and sandstones flank and rest unconformably upon the granites and porphyries. The iron ore of Iron Mountain and most of the other localities is in veins in the massive rock, probably of water infiltrated origin; or in a residuary mantle; or as concentrated detritus along the slopes or ravines of the porphyries. In the two latter cases the ore is derived from the veins. In some cases this concentration occurred before or during the deposition of the Cambrian sandstones and limestones, but in other cases is subsequent to the deposition of these rocks. At Pilot Knob the succession from the base upward is porphyry; conglomerate; a slaty ripple marked stratum in contact with the ore body; main ore body, nineteen to twenty-nine feet thick; highly ferruginous slate, one to three feet thick; heavy beds of conglomerate with an average thickness of one hundred feet. The pebbles of the conglomerate are mainly derived from the porphyries, but the regularly laminated slate and ore have a thin bedded structure, which is such as to lead to the conclusion that they are undoubtedly of sedimentary origin.

Bell[2] gives a general account of the Laurentian and Huronian systems, and a sketch of the geology of the country extending from Lake Huron northward to Lake Temiscaming, and from Lake Nipissing westward to the Spanish river. The Laurentian system is divided into an upper and a lower formation. The latter consists almost entirely of fundamental gneiss, while the upper Laurentian appears to consist of metamorphosed and sedimentary strata, to some extent at least.

The lower division of the Laurentian consists of red and gray gneiss, usually much bent or disturbed, and having generally a rudely foliated structure, and a solid or massive character. The feldspar is almost entirely ortho-

[1] *The Iron Ores of Missouri*, by Frank L. Nason. In Rep. Geol. Sur., Missouri, for 1891–2, Vol. 2, pp. 16–69. Jefferson City, 1892.

[2] *The Laurentian and Huronian Systems North of Lake Huron, accompanied by Geoolgical Map.* Dr. Robert Bell, Rep. of Bureau of Mines, Ontario, 1891, pp. 63–94. Toronto, 1892.

clase. The upper division of the Laurentian is more complex. It possesses more regularity in stratification and includes great banded masses of crystalline limestones, vitreous quartzites, mica-schist and hornblende-schist, massive pyroxene, and massive and foliated labradorite rocks. Considerable areas of granite and syenite occur in the formation. The Upper Laurentian of the Ottawa valley may be roughly estimated to be at from 50,000 to 100,000 feet in thickness.

While the older Laurentian rocks afford no proof of the permanent existence of the sea upon the earth, water appears to have been present, perhaps only as precipitations upon the surface, at every stage of its formation. But the deposits of limestone and tolerably pure silica in distinct bands in the Upper Laurentian afford strong support to the aqueous theory of its deposition.

With the beginning of the Huronian period great volcanic activity began, and there is evidence of the permanent abode of water on the surface of the earth. The general character of the Huronian rocks may be said to be pyroclastic, by this signifying that, although fragmental, they have nevertheless had an igneous origin.

The area mapped between the Huronian belt and the shore of Georgian bay appears to belong to the Upper Laurentian. The rocks are gneisses of the typical Laurentian varieties, finely stratified and regularly arranged in anticlinal and synclinal folds, the angles of dip usually not being far from forty-five degrees, but lesser and greater dips being found. Red and gray varieties are about in equal proportion, and they alternate with each other in thick and thin sheets. Mica-gneisses are predominant. No beds of crystalline limestone are found west of Iron Island in Lake Nipissing. Limestones are associated with the gneisses on some of the islands of the eastern part of this lake and at Lake Talon on the Mattawa. In the Parry Sound district are five distinct bands of Laurentian limestone. These rocks are classified with the Upper Laurentian rocks of the counties of Ottawa and Argenteuil.

The Laurentian rocks northwest of the Huronian belt are heavy contorted gneisses of the lower Laurentian. Associated with the gneisses are red granites which are classed with the Laurentian, but which may be really Huronian. These may have formed by softening the gneiss by heat, combined with re-crystallization, or they may be due to the alteration of the Huronian arkoses or graywackes, or they may be mainly eruptive. These granites are along the contact line between the Laurentian and Huronian. Along the line of contact between the granites and Huronian quartzites and schists, the rocks are much broken. It is not improbable that a fault exists at the line of junction between the Laurentian and Huronian rocks.

The great Huronian belt consists of a great variety of rocks, such as crystalline schists, quartzites, conglomerates, agglomerates, clay-slates, greenstones, dolomites, etc., the majority of which are pyroclastic. The rocks are

received successive coats of other kinds of rock in after ages. The most dissimilar series of formations are known to be of the same age. What is happening to-day has happened in all ages. Nothing could be more unlike than the deposits now forming along the various ocean shores, and in different lakes and inland seas; yet they are all of one age. Even the deposits making in one and the same basin radically differ; as, for example, along the northern and southern sides of Lake Ontario; and along the eastern and western sides of Lake Champlain. It would therefore seem a useless task to seek for the Huronian rocks far from their native range.

Nason[1] fully describes the iron ores of the porphyry region of Missouri, and incidentally treats of the associated rocks. The porphyries usually show evidence of bedding, but this may be that of igneous flows. The Cambrian limestones and sandstones flank and rest unconformably upon the granites and porphyries. The iron ore of Iron Mountain and most of the other localities is in veins in the massive rock, probably of water infiltrated origin; or in a residuary mantle; or as concentrated detritus along the slopes or ravines of the porphyries. In the two latter cases the ore is derived from the veins. In some cases this concentration occurred before or during the deposition of the Cambrian sandstones and limestones, but in other cases is subsequent to the deposition of these rocks. At Pilot Knob the succession from the base upward is porphyry; conglomerate; a slaty ripple marked stratum in contact with the ore body; main ore body, nineteen to twenty-nine feet thick; highly ferruginous slate, one to three feet thick; heavy beds of conglomerate with an average thickness of one hundred feet. The pebbles of the conglomerate are mainly derived from the porphyries, but the regularly laminated slate and ore have a thin bedded structure, which is such as to lead to the conclusion that they are undoubtedly of sedimentary origin.

Bell[2] gives a general account of the Laurentian and Huronian systems, and a sketch of the geology of the country extending from Lake Huron northward to Lake Temiscaming, and from Lake Nipissing westward to the Spanish river. The Laurentian system is divided into an upper and a lower formation. The latter consists almost entirely of fundamental gneiss, while the upper Laurentian appears to consist of metamorphosed and sedimentary strata, to some extent at least.

The lower division of the Laurentian consists of red and gray gneiss, usually much bent or disturbed, and having generally a rudely foliated structure, and a solid or massive character. The feldspar is almost entirely ortho-

[1] *The Iron Ores of Missouri*, by Frank L. Nason. In Rep. Geol. Sur., Missouri, for 1891–2, Vol. 2, pp. 16–69. Jefferson City, 1892.

[2] *The Laurentian and Huronian Systems North of Lake Huron, accompanied by Geological Map.* Dr. Robert Bell, Rep. of Bureau of Mines, Ontario, 1891, pp. 63–94. Toronto, 1892.

clase. The upper division of the Laurentian is more complex. It possesses more regularity in stratification and includes great banded masses of crystalline limestones, vitreous quartzites, mica-schist and hornblende-schist, massive pyroxene, and massive and foliated labradorite rocks. Considerable areas of granite and syenite occur in the formation. The Upper Laurentian of the Ottawa valley may be roughly estimated to be at from 50,000 to 100,000 feet in thickness.

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usually tilted at high angles. There are numerous instances where there is a gradual transition from the Huronion to the lower series. A few instances of local want of conformity between the two is no evidence that the two systems are not conformable on a grand scale. The few known instances where there appears to be a want of parallelism are more probably due to faulting. The pyroclastic rocks show the agency of water in their formation, and were largely derived from igneous matter, which had been more or less recently erupted. The newest rock of the Sudbury district is a volcanic breccia, which forms a continuous range of hills for a distance of thirty-six miles, with a breadth in the center of eight miles. Within the Huronian rocks are intrusive red granites.

Comments. Attention is called to the implication that the unconformity at the base of the Huronian, if it exist at all, is of a local character. The very idea of an unconformity pre-supposes that it can not be local in the narrow sense. A minor unconformity even marks a considerable time break, and when an earlier series has been profoundly metamorphosed and deeply denuded before the overlying series is deposited upon it, the break must be of regional extent, even if the contacts found are few and of small extent. It, however, does not follow that the break is universal nor even that it always extends throughout a geological basin. Space does not permit a discussion of the evidence for the existence of unconformable contacts at the base of the original Huronian in certain localities. It is enough to say that Irving, Pumpelly, Reusch, Barrois, and Tschernychew, all having seen one of the localities and the first two both, agree that the only interpretation of the phenomena at points near Garden river and near Thessalon is that of a great unconformity, not faulting as suggested by Bell, who does not appear to have ever visited these localities.

Barlow [1] states that the Huronian system is the oldest sedimentary strata of the north shore of Lake Huron, and that the Laurentian gneiss or Basement Complex is the original crust of the earth or floor on which the first sediments were laid down. This floor, as shown by the pebbles of the Huronian, was granite which had in many places a foliated or gneissic structure. In many places the subsequent folding and fracturing of the comparatively thin crust of the earth has caused large portions of the Huronian to sink below the plane of fusion, the result of which has been to produce irruptive contacts. At other places, as described by Pumpelly and Van Hise, the Basement Complex may have remained undisturbed so that the overlying detritals have not been intruded by the granitic mass beneath.

Hall and Sardeson [2] describe the Upper Cambrian rocks of Southeastern

[1] *On the relations of the Laurentian and Huronian on the North Side of Lake Huron.* Alfred E. Barlow. Am. Jour. Sci., 3d series, vol. 44, 1892, pp. 236–239.

[2] *Paleozoic Formations of Southeastern Minnesota.* C. W. Hall and F. W. Sardeson. Bulletin Geol. Soc. of America, vol. 3, 1892, pp. 331–368.

Minnesota as resting unconformably upon a pre-Paleozoic floor. The base of the Potsdam is usually conglomeratic. At Minneopa a well 800 feet deep passed through a conglomerate for a distance of 225 feet, the pebbles of which are vitreous quartzite like those occurring in Cortland, Watonwan and Cottonwood counties. A conglomerate containing granitic debris is found on Snake river about two miles above Mora, and three miles distant from the Ann River knobs of hornblende-biotite-granite, the clastic appearing to be derived from the granite. At Taylors' Falls a conglomerate made up of pebbles of diabase rests upon the diabase of the St. Croix river. These underlying formations are Archean and Algonkian rocks.

Grant [1] states that the Animikie rests unconformably upon the Saganaga granite; that the Ogishki conglomerate is intruded by the Saganaga granite, and therefore that the Ogishki conglomerate is earlier than and separated by a great structural break from the Saganaga granite. As the Keewatin has the same relations to the Saganaga granite as the Ogishki conglomerate, the same thing is true of the Animikie and Keewatin. The Ogishki conglomerate is younger than the most of the Keewatin, but is considered as a part of it.

Comments :—The most characteristic and abundant fragments in the Ogishki conglomerate are granite. The rock occurs in pieces running from those of minute size to great bowlders. It is manifest that this material was derived from a pre-existing granite. These bowlders are in all respects like much of the Saganaga granite, and the probability is very strong that this is their source. Grant is probably correct as to the intrusion of the conglomerate by a granite, but this granite may have also intruded the main Saganaga mass. The too frequent mistake has apparently been made of concluding that in the Saganaga area there is granite of but one age, when frequently in the great massives of the Northwest, granites of several ages occur, the latest ones cutting all the previous ones, and often the far newer clastics. It further follows that the implication that the Animikie is unconformably upon the Ogishki conglomerate needs the support of additional evidence. That this conglomerate is possibly more nearly related to the Animikie than to the Keewatin is shown by the presence of abundant jasper fragments, presumably derived from the Keewatin. The article appears to be another illustration of the facts being right, the author in his interpretation, however, overlooking a part of the facts which are to be accounted for in making a true generalization.

Winchell [2] gives a review of the literature on the Norian of the Northwest. Here are included the gabbros, placed as the basement member of the

[1] *The Stratigraphic Position of the Ogishke Conglomerate of Northeastern Minnesota*, U. S. Grant. Am. Geologist, vol. 10, 1892, pp. 4–10.

[2] *The Norian of the Northwest*, by N. H. Winchell. In Bull. 8, Geol. and Nat. Hist. Sur., Minn. 1893, pp. iii–xxii.

Keweenawan by Irving, and the Bohemian Mountains of Keweenaw Point. It is suggested that the anorthosites of Lawson are but facies of the gabbro, and that the two belong together in the Norian.

Comments :— This paper correlates with the so-called Norian of the East the gabbros and similar rocks of the Lake Superior region, which have heretofore been considered as constituting a part of the Keweenawan. Such lithological correlations are believed to retard, rather than advance geological progress, as they rest wholly upon unverified assumptions. The local name Keweenawan ought to be retained for the gabbros and allied rocks, or else some new local name ought to be devised for it. This latter is done by Lawson as appears from the paper next summarized.

Lawson[1] gives a petrographical and structural account of the anorthosites of the Northwest shore of Lake Superior. The anorthosite is wholly massive, completely granitic in structure, and is composed almost wholly of basic feldspar, varying in composition from labradorite to anorthite. The rock occurs near Encampment Island, in the vicinity of Split Rock point, at Beaver Bay and vicinity, at Baptism river, on the slopes of Saw Teeth mountain, and at Carlton Peak. In nearly all of these localities the rock is found in rounded dome shaped masses below the other eruptives of the coast. It is cut by these different eruptives, and in the lava flows are found very numerous blocks and bowlders of anorthosite, which were caught in at the time of their extrusion. These facts show that the anorthosite is of pre-Keweenian age, and since the anorthosite is a plutonic rock, it must have suffered profound erosion prior to the extravasation of the Keweenian eruptives. Norwood, Irving and Winchell have described the blocks of anorthosite in the lavas at some of the points. Winchell regarded the anorthosite at Split Rock as older than the eruptives containing masses of them, and Irving reached the same conclusion in reference to the anorthosite at Carlton Peak. However, none of them differentiated the anorthosite mass from the general aggregation of volcanic flows, constituting the Keweenian series of the Minnesota coast. The surface of the pre-Keweenian anorthosite is domed and hummocky like that of the other Archean terrains of Canada, and it is thought to have been only modified by Pleistocene erosion. The interval between the anorthosite and the Keweenian is probably the same as the pre-Paleozoic interval which effected the reduction of the Archean to the great hummocky plain, to which it was reduced before the Animikie was deposited upon it. As the Keweenian rests directly upon the anorthosite, the Animikie is absent for the middle third of the Minnesota coast. Irving places the thickness of the Keweenian of the area at 20,000 feet, stating that it may reach 22,000 or 24,000 feet. The maximum thickness of the

[1] *Anorthosites of the Minnesota Shore of Lake Superior*, by A. C. Lawson. In Bulletin 8, Geol. and Nat. Hist. Sur., Minn., 1893, pp. 1–23.

Keweenian is not more than one-tenth of this thickness. Irving's subdivision of the Keweenian into groups, and his estimate of the thickness of various portions of the series are of little value; a statement which it is as painful to make as it is necessary in the interests of sound geology. The anorthosite is provisionally correlated with the Norian of the Province of Quebec, but as this correlation is merely a hypothesis, the name Carltonian is suggested for this formation.

Comments :—The main structural conclusion of Lawson, that the anorthosite of the Northwest shore of Lake Superior is older than and was deeply eroded before the deposition of the upper Keweenawan lava flows, seems clearly established, and this is a conclusion of great importance. However the general inferences which are drawn from this relation call for more evidence.

At the outset it is to be noted that the term Paleozoic is extended to include the Keweenian and Animikie series, a usage not followed by many and involving a great proposition which demands evidence. The question is, however, too large to discuss here.

The Keweenaw series of Northeastern Minnesota is of great extent and thickness. Irving, in his latest paper on the pre-Cambrian divided the Keweenawan into two divisions, a lower basal gabbro, and an upper series, consisting of thinly-bedded basic and acid rocks.[1] The anorthosite is but a facies of gabbro, in which the pyroxenic constituent is reduced to a minimum. The most probable explanation of the relations made out by Lawson, as it appears to me, is that the anorthosite exposed on the coast belongs with this great basal gabbro, and this is the position which is apparently favored by Professor Winchell,[2] although he regards the whole gabbro mass as pre-Keweenawan. This latter is a matter of definition, and is contrary to the general usage of the term in the past, both divisions having been generally regarded as making up the Keweenawan. The length of the period represented by the Keweenawan was so great, that after the outflow or intrusion of the basal gabbro there may have been along the Minnesota coast a period of erosion, thus cutting deep into the gabbro, anorthosite and associated rocks. Later in Keweenawan time this eroded surface was covered by the flows of the upper division. Indeed this unconformity between the basal gabbro of the Keweenawan and the upper, more thinly-bedded members of the series was noted by Irving[3] both for the Bad River area of Wisconsin and for Minnesota, and is

[1] *The Classification of Early Cambrian and pre-Cambrian formations*, by R. D. Irving. In 10th Annual Rep. U. S. G. S., pp. 418–420.

[2] *The Norian of the Northwest*, by N. H. Winchell. In Bull. Nat. Hist. and Geol. Sur., Minn., pp. 28, 19.

[3] *Copper Bearing Rocks of Lake Superior*, by R. D. Irving. In Third Annual Rep. of Director U. S. G. S., pp. 134, 136, 137. Also Mon. 5, U. S. G. S., pp. 155, 156, 158, 159.

reinforced in the latter case by his map of Northwestern Minnesota, which suggests that the upper division of the Keweenawan overlaps the lower unconconformably.

In the first of these areas the thin-bedded flows are described as being poured out against the gabbro mass, which, it is said, must have stood to a great height, until finally the flows accumulated sufficiently to cap the upper surface of the gabbro. So strongly was Irving impressed by these facts, that he states that he was inclined at first to place the gabbros of the Bad River district with the Huronian, and to regard them as the equivalents of the great flows of the Animikie series of Thunder Bay, but, finding the Animikie slates unconformably under the gabbros, he preferred to put them as the earliest division of the Keweenawan, clearly recognizing that there was a very considerable unconformity between these coarse, massive rocks and the later thinly-bedded ones. This reference was made because of the close lithological relationship of the gabbro and the Keweenawan diabases, and because in eruptive series such breaks were regarded as less significant.

It thus appears that Irving fully appreciated an unconformity, probably at the horizon of Lawson's unconformity, but he did not recognize that the break which has so extensive an occurrence also exists along the Minnesota coast. If the explanation suggested as to the relations on the Minnesota coast be true, Irving's statements, used in reference to the Bad River area, can be applied almost exactly to this one, in which case the difference between Irving and Lawson is that of nomenclature. Lawson restricts the term Keweenawan to the upper part of the series, whereas Irving and other writers regarded the Keweenawan as including both divisions. It also follows, if the anorthosite is Keweenawan, that Lawson's conclusion that the Animikie is absent below the Keweenawan in Northeastern Minnesota, is without foundation, for the base of the Keweenawan thus defined is not here exposed. Further, the Animikie is certainly unconformably below the great basal gabbro of Minnesota. It further follows that the correlation of the anorthosites of Lake Superior and those of the Province of Quebec has no value. But, wholly apart from the stratigraphy of Northeastern Minnesota, I must confess to a complete lack of confidence in the correlation of eruptive rocks so far removed as these.

To the statement that Irving's subdivision of the Keweenawan into groups and his estimate of the thicknesses of various portions of the series are of little value, I feel that I must take exception. The painstaking character of all of Irving's work is well-known. He spent many years of study upon the series in Michigan and Wisconsin. His study, and that of his assistants, Messrs. Chauvenet, Cambell and McKinley, on the northwest coast of Lake Superior was of a detailed character. It would seem scarcely possible that Dr. Lawson's study of the stratigraphy in a single trip, in which he made no attempt to re-measure the sections (so far, at least, as can be ascertained from his paper) could have been detailed enough to warrant this sweeping state-

ment. On one point Irving seems not to have fully drawn the conclusion which legitimately followed from his observations. This, however, does not invalidate the observations in any way, nor lessen the strength of the many important conclusions which were reached. The only particularized notice by Dr. Lawson of these supposed errors is in reference to the thickness of the Keweenawan. The statement that Irving overestimated this thickness tenfold certainly needs additional justification. The thicknesses given are maxima for the particular region. Irving was perfectly well aware that the Keweenaw series varies greatly in thickness from place to place, being largely of volcanic origin. He also knew that it varies from its maximum thickness to entire disappearance at a not very remote distance from the Lake Superior basin. That a volcanic series is not of great thickness in one particular area of a region is no evidence that it is not so in other parts. If the anorthosite division of the Keweenawan constituted a mountainous mass for the central part of the Minnesota coast, and the upper Keweenawan beds were deposited against them, as before suggested, these later beds may have a very great thickness remote from the anorthosites, or at the inaccessible base of the past mountain range, and this would be quite in accordance with a moderate thickness near the tops of the anorthosite domes.

Lawson[1] describes the laccolitic sills of the northwest coast of Lake Superior. The trap sills are mainly diabases, but they occasionally pass into gabbros. It is held that there are no contemporaneous volcanic rocks in the Animikie group, and that the trap sheets are intrusive in their origin, rather than subsequent volcanic flows, for the following reasons: They are simple geological units, one not overlapping another; they have a uniform thickness over areas more than 100 square miles in extent; where inclined, the dip is due to faulting and tilting; they have no pyroclastic rocks associated with them; they are not glassy nor amygdaloidal; they show no flow structure, or other distinct properties of effusive rocks; their contacts with the slates are sharp; they never repose upon a surface which has been exposed to weathering or erosion; they are analogous to the great dikes of the region in all their relations; they may be observed in direct continuity with dikes; they pass from one horizon to another; they have a columnar structure extending throughout their thickness; apophyses pass from the main sheets into cracks of the slate above and below; they locally alter the slates above and below them.

The Animikie strata have been dislocated by a great system of faults, the orographic blocks having been frequently tilted. The non-recognition of this prevalent tilted structure has led to very excessive estimates of the thickness of the series by Irving and Ingalls. In the vicinity of Black Sturgeon River

[1] *The Laccolitic Sills of the Northwest Coast of Lake Superior*, by A. C. Lawson. In Bull. 8, Geol. and Nat. Hist. Sur., Minn., pp. 24–48.

and on the Isles of Nipigon Bay are numerous places where Keweenian strata are capped by thick sheets of trap, identical with those which cap the Animikie, but, though these sheets cannot be traced in absolute continuity in the interval, there are many outlying patches which fill the gap. The same trap sheets are found in several instances to pass from the Animikie to the Keweenian, and there are the same evidences of intrusion of independent trap sheets in the Keweenian that are in the Animikie. These rocks are, therefore, of post-Keweenian age, and, to discriminate them from the Keweenian and Animikie, they are designated the Logan sills.

Comments :— The fact that all the trap sheets of the Animikie studied by Lawson are intrusive is no evidence that in other areas, not studied by him, there may not be contemporaneous volcanics. The traps in the Triassic of Connecticut and New Jersey are an illustration of this point, a part of them being extrusive and a part intrusive. Also in the Penokee series, the equivalent to the Animikie series, while for the main part of the area there are no contemporaneous volcanics, in the eastern end of the series there suddenly appears a great thickness of contemporaneous volcanic fragmentals, and such may occur in the Animikie in the areas not yet studied.

The inclination of the Animikie series was fully recognized by Irving and Ingall, and this it was which led them to make their estimates of the thickness. The statement, that the strata have been dislocated by a great system of faults, may be true, but in the paper it is not supported by any evidence; and, until detailed evidence is presented, the conclusion of Irving and Ingall as to the thickness seems more probably true than the hypothesis of numerous faults.

Because the sills are later than the Animikie and Keweenawan strata which they have intruded, is no sufficient evidence that they are post-Keweenawan. The thickness of the Keweenaw series is so great that it is quite reasonable to expect that correlative with the later extrusions were intrusions between the older Keweenawan strata. To explain all the facts cited on the northwest coast it is only necessary to suppose that the upper part of the Keweenawan has been removed by erosion, and that the sills now composing the upper layers in these places were overlain at one time by higher members, which have subsequently been removed by erosion. This is not a violent supposition, for it is well known that erosion and volcanic extrusion alternated many times in single areas during Keweenawan time.

C. R. VAN HISE.

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